SOLDERING
CAST GOLD ALLOYS

This thesis, based upon an original study by the author, is submitted to the University of Sydney in support of my candidature for the degree of Master of Dental Surgery.

Frank T. P. Liu

Frank T. P. Liu, B.D.S.
February, 1969.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgements</td>
<td>(i)</td>
</tr>
<tr>
<td>Introduction</td>
<td></td>
</tr>
<tr>
<td>Review of Literature</td>
<td></td>
</tr>
<tr>
<td>Method of Soldering</td>
<td>1</td>
</tr>
<tr>
<td>Effect of Soldering on Parent Metals</td>
<td>12</td>
</tr>
<tr>
<td>Properties of Gold Solder</td>
<td>15</td>
</tr>
<tr>
<td>One Piece Casting</td>
<td>22</td>
</tr>
<tr>
<td>Fit of Soldered Constructions</td>
<td>26</td>
</tr>
<tr>
<td>Microstructure of the Soldered Joint</td>
<td>29</td>
</tr>
<tr>
<td>Porosity in Casting</td>
<td>32</td>
</tr>
<tr>
<td>Methods of Casting</td>
<td>37</td>
</tr>
<tr>
<td>Types of Gold</td>
<td>41</td>
</tr>
<tr>
<td>Heat Treatment of Gold Alloys</td>
<td>47</td>
</tr>
<tr>
<td>The Original Investigation</td>
<td></td>
</tr>
<tr>
<td>The Scope of The Investigation:</td>
<td>54</td>
</tr>
<tr>
<td>Materials and Methods:</td>
<td></td>
</tr>
<tr>
<td>Specimen Preparation</td>
<td>55</td>
</tr>
<tr>
<td>Soldering</td>
<td>55</td>
</tr>
<tr>
<td>Heat Treatment</td>
<td>61</td>
</tr>
<tr>
<td>Test Methods</td>
<td>62</td>
</tr>
<tr>
<td>Results:</td>
<td>63</td>
</tr>
<tr>
<td>Basic Factors on Parent Metals and Soldered Joints</td>
<td>69</td>
</tr>
<tr>
<td>Soldering Variables</td>
<td>69</td>
</tr>
<tr>
<td>Effects of Soldering and Heat Treatment on Physical Properties</td>
<td>77</td>
</tr>
<tr>
<td>Contact Point Soldering</td>
<td>84</td>
</tr>
<tr>
<td>Tensile Tests</td>
<td>89</td>
</tr>
<tr>
<td>Bend Tests</td>
<td>91</td>
</tr>
<tr>
<td>Conclusions and Discussion</td>
<td>94</td>
</tr>
<tr>
<td>Summary:</td>
<td>97</td>
</tr>
<tr>
<td>Bibliography</td>
<td>109</td>
</tr>
</tbody>
</table>
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The author would also like to thank Miss J. M. Goldhawk for her expert typing of this thesis, and other members of the staff of the Department of Operative Dentistry for their advice and constructive criticism.
INTRODUCTION.

Soldering procedures have long held an important place in dentistry and it is somewhat surprising that very few basic studies have been conducted on the soldering operation.

As Crown and Bridgework assumes a more important place in dental practice, a sound basis for the joining of cast gold structures, with gold solder, becomes essential.

Much of the standard work on gold solders was done at the National Bureau of Dental Standards, Washington, prior to 1940. The most important paper published more recently is that by Ryge (1958) in which the nature of the gold soldered joint was studied, after soldering at varying temperatures and with varying gap sizes. Ryge did not give any indication of whether soldering was carried out electrically or using a gas-air blowtorch. The relationship of Ryge's work to clinical practice is a little uncertain.

The initial aim of this research project was to investigate the metallurgy of joints soldered, using methods commonly employed in dental laboratories.

It soon became obvious that one could not study the soldered joint without a study of the parent alloys. The scope of the investigation was therefore widened to include these materials. Naturally this involved a study of various
casting methods and different types of casting gold alloys as well as the many physical variables concerned with the gold soldering operation itself.

Naturally when one studies the broad aspects of such a procedure, depth must be sacrificed in some areas. It is felt, however, that the study has produced some worthwhile findings which in some small way, help to advance the science and art of dentistry.
METHOD OF SOLDERING

Soldering is an old art. It has been practised in dentistry for a long time and has been developed on the basis of soldering and brazeing practices used in the jewellery trade.

In modern dental procedures gold solders are used for the joining of cast gold pontics and abutment crowns in bridgework, and for the joining of wires and other wrought appliances to each other or to orthodontic or prosthetic appliances. Occasionally solder is also used to build up a contact area of a gold inlay or crown. But the techniques employing building solder for the forming of lingual or occlusal surfaces of crowns to a great extent have been abandoned. Building solders were formerly used extensively in dentistry for the actual formation of crowns.

Skinner and Phillips (1967) defined soldering as the joining of metals by the fusion of intermediary alloys which are of a lower melting point. The lower fusion metal which is the solder, is fused to the parts to be joined.

Jelenko (1964) stated "that it is essential that the solder unite with the parent metal uniformly and at all points throughout the joint. A joint very often exhibits an obvious union at the edges but with hidden discontinuities within the joint".
Anderson (1967) pointed out that when a solder is melted between two pieces of metal, it should alloy slightly with the surface layers. Then the solder forms a continuous metal structure across the joint, and the crystal grains of the metals which are soldered become continuous with those of the solder itself. Between the atoms of the solder and the solid metal in the new intermediate alloy, strong intermetallic bonds are created.

He also mentioned that it is, however, possible to make a soldered joint in which little or no alloying takes place. This occurs when a relatively low-fusing solder is used to join together metals with a high melting point. Provided that the atoms of the solder and of solid metal come into close contact, a good adhesive bond is produced.

Peyton et al (1964) stressed that there should be no fusion of the metal or alloy structures to be joined by the solder. The solder must possess, therefore, a sufficiently low fusion temperature so that it will melt and flow before the parts being joined are melted.

Ryge (1958), however, reported, in contrast to common belief, a strong solder junction can be obtained without noticeable diffusion between the solder and the parent alloy. Normal dental soldering should be carried out at temperatures which do not cause considerable diffusion. Overheating with
resulting diffusion is undesirable since it results in reduction in strength and ductility because of grain growth.

He stressed that prolonged and excessive heating not only cause diffusion but also results in increased contraction at the solder junctions.

METHODS OF SOLDERING.

Dental soldering nowadays can be done in two ways: free hand soldering and investment soldering.

Free hand soldering technique is commonly used in the assembly of orthodontic appliances, in building up contact areas of inlays or crowns and occasionally in the soldering of a perforation in the occlusal of a crown where the surrounding area is rather heavy.

For soldering orthodontic appliances the parts to be assembled are held manually in contact while the heat and solder in wire or strip form are applied. As soon as the solder has flowed to position, heat is removed.

For contact point soldering and repairing perforations in inlays and crowns, the restoration is first dentally polished and the area which requires building up or repair is outlined with a pencil which acts as an antiflux restricting the flow of the solder to unnecessary areas. A small piece of solder coated slightly with flux is placed onto the area.
and the restoration is held over the reducing area of a bunsen flame till the solder flows.

In investment soldering, the parts to be joined are first assembled and the joint areas are waxed up and then invested in a soldering investment which has little or no setting expansion. After at least 45 minutes setting time, the parts to be joined are actually held together for soldering by the soldering investment. The wax is then removed with boiling water and flux in paste form is applied to the areas to be soldered while the invested assembly is still warm.

The assembly is heated over a low gas flame and heating is gradually increased over a period of 30 minutes till the invested assembly becomes a uniform dull red which indicates a temperature of $1200^\circ$ to $1300^\circ$F (Anderson 1967).

The actual soldering is commonly carried out with a gas-air blowpipe. Small pieces of fluxed solder are placed on the joint areas. The reducing portion of the flame is used and heat is removed as soon as the solder flows. The soldered assembly is allowed to cool and then quenched. Pickling is carried out before final polishing of the assembly.

Soldering in an electric furnace is sometimes carried out (Peyton et al 1964). The fluxed pieces are placed at the joint areas at the preheating stage and soldering is completed when the solder starts to flow. Overheating is more easily
avoided this way than with the use of gas-air blowpipe.

Ante (1918) listed the essential requirements for successful soldering as follows:

(i) Cleanliness of the surfaces,
(ii) Proper flux,
(iii) Apposition of surfaces,
(iv) A free flowing solder,
(v) Proper amount and distribution of heat,
(vi) Proper support.

Ante (1918), Ryge (1958), Shell (1962), Skinner and Phillips (1967), Peyton et al (1964), Anderson (1967) and Wetterstrom (1968) all maintained that parts to be joined in soldering must be clean and free of dirt, oxides and grease so that the solder will flow easily and freely with the best wetting action. Ante and Ryge both suggested pickling the parts to be joined in acid (sulphuric acid). This will remove all oxidation and deposits of foreign character contaminated by polishing agents. Ryge (1958) also mentioned that crowns, bands and other appliances which have been fitted on fusible metal dies should be boiled in nitric acid to remove traces of metal before soldering.

FLUXES.

A good flux is a vital adjunct to soldering operations.
The surfaces to be soldered must be protected from oxidation during preheating and soldering procedures. This can be prevented by using a good reducing flux. Such a flux has a greater affinity for oxygen present than the base metals in the gold alloys. It picks up any oxygen present and keeps it away from the gold alloys. The flux should be applied immediately after wax elimination with boiling water. The warmth of the soldering block will melt the flux smoothly and evenly over the entire surface to produce a clean easily wet surface which ensures good flow for the solder. Fluxes come in powder, liquid and paste forms. The paste fluxes are usually desirable to use because of the greater ease of obtaining a complete coverage of the desired area. Only a thin coating of flux should be used.

Areas on which no solder is desired may be covered with an antiflux. This is especially important in contact area and repairing perforation type of soldering. Pencil lead is an excellent antiflux. Others are whiting, rouge with chloroform or alcohol.

GAP DISTANCE.

The correct gauging of the distance between the parts to be soldered is a matter of importance for the prevention of warpage or distortion of the parts.
Theoretically, the distance between the parts should be related to three factors: (i) the thermal expansion of the investment during setting and heating, (ii) the thermal expansion of the parts, and (iii) the shrinkage of the solder during solidification.

Unfortunately, the above relationships have not been subjected to detailed analyses.

The gap distance between the parts to be joined has therefore been a controversial topic.

Some maintain that the pieces to be soldered should be in contact. Ante (1918) stated that to facilitate the union between the parts, the edges or surfaces should be in absolute contact and solder would run freely by the force of capillary attraction between two closely fitted surfaces, just as water between two pieces of glass.

Steinman (1954) stated that the more precise the fit of the parts to be soldered, the less they will be distorted.

Recent studies by Anderson, Fairhurst and Ryge (1958) & Hollenbeck, Smith and Shell (1966) however, have demonstrated that if the parts to be soldered are in contact before heating, distortion will occur. Ryge (1958) also found that porosity occurred much more frequently with small gap distances.

The following figures are the gap distances recommended by the different investigators:
0.005" (0.1 mm.)  Skinner and Phillips (1967).
0.005" Minimum  Ebye (1958).
0.01" (3 thicknesses of letter paper)  Jelenko (1964).
0.01" Minimum  O'Brien (1960).
0.15 - 0.20 mm. (1-3 tin foil gauges)  Anderson (1967).
0.003" - 0.006"  Hollenback, Smith and Shell (1966).
0.1" - 0.25"  Tylman

The average gap distance would be 0.005" - 0.01", according to these investigators.

It is suggested by Jelenko (1964) that it is desirable to make the gap as small as possible, while at the same time avoiding contact of the parts to be soldered during burnout and heating in the flame.

**SELECTION OF GOLD SOLDERS.**

Every soldering operation calls for a specific type of solder. When selecting a solder for a particular soldering operation, the physical properties of the solder and of the parent metal are extremely important, particularly the melting range of each. Wetterstrom (1968), Skinner and Phillips (1967) & Peyton et al (1964) maintained that the upper melting range of the solder should not come within 100° - 180°F of the lower
melting range of the parent alloy to avoid any possibility of changing the physical properties of the parent alloy.

Skinner and Phillips (1967) and Peyton et al (1964) pointed out that gold solder with a low surface tension is desirable for successful soldering.

Ryge (1958) suggested the use of gold solder of high "fineness", as its structure and the response to heat treatment are likely to be closer to those of gold alloys. Also, fine solders have better flow characteristics than solders of low fineness, so the use of a fine solder will result in reduced heating time during the actual soldering; whereas low fineness solders often have a tendency to ball up. Solders of high fineness have an additional advantage if the work piece requires additional soldering or repair. Solder of slightly lower melting range can then be selected without having to use solder of fineness so low that there is danger of corrosion and discoloration.

For building up an area, Wetterstrom (1968) suggested using a wide melting range solder so that it can actually fuse with the parent metal and still not go into a complete flow.

Solders of .650 fineness or above are commonly used for soldering operations demanding the building up of the restoration, whereas solders of .650 fineness or below are
used in assembled operations. Building up characteristic of gold solders, however, is not so important today as it was in the period when "solder" bridges predominated in the field of bridgework.

Solder is usually supplied in the form of wire or strip. Skinner (1954) stressed that the smallest amount of solder possible which will ensure a complete and continuous union should be used. An excessive amount of solder produces an area of weakness and a greater susceptibility to corrosion and tarnish. Steinman (1954) stressed that the less solder used, the less distortion produced.

HEATING.

The application and proper manipulation of heat in securing the best results is an important feature and a matter requiring both care and judgment. For free hand dental soldering the work is more easily accomplished, but when investment is used, the process is a more complicated task.

For pre-heating, the invested assembly is normally placed on a wire grid over a gas burner. It is heated with a low flame which is gradually turned up high and maintained until the invested assembly becomes a uniform dull red.

Pre-heating may be carried out in an electric furnace. Kovaleski (1958), Meyer (1959) & Ryge (1958), however, stressed
the importance to obtain an even and preferably controlled rapid pre-heating of the whole workpiece to a temperature close to the melting range of the gold solder in a temperature controlled furnace and be allowed to remain in this uniform atmosphere for 30 minutes or longer. Even application of heat during pre-heating of the assembly will therefore make it possible to avoid distortion of the invested assembly block.

The type and adjustment of the soldering flame are most important for actual soldering procedures. The flame must be large enough to cover the joint to be soldered, but no larger. It should cover the joint in order to ensure a decoxidizing atmosphere in all parts, thus avoiding the problems resulting from oxide formation in the solder. It should not exceed this size lest it impinge unduly on the adjacent investment, thus increasing the danger of releasing contaminating sulphur from the investment.

The flame of an ordinary gas-air blowpipe, properly adjusted, is entirely satisfactory for soldering purposes. Hollenbeck, Smith and Shell (1966) suggested that the blowpipe flame for soldering should be smaller than that used for casting but with the same well defined and pointed flame.

Ryge (1958) maintained that the actual soldering should be accomplished in a few seconds.
EFFECT OF SOLDERING ON PARENT METALS.

Metals and alloys in the solid state are composed of grains which may be of different size depending upon many factors including the effect of soldering. The cooling rate after solidification has little or no effect on the grain size.

Metallurgists in general maintain that a smaller grain size makes for better physical properties in the metal and is therefore desirable.

Skinner and Phillips (1967) agreed that the smaller the grain size of the metal, the better will be its physical properties. Consequently, the obtaining of a small grain size during casting and soldering is an advantage. The smaller and the greater the number of these grains per area, the stronger a particular metal or alloy will be.

Peyton et al (1964) stressed that, within certain limits, the smaller the grain size, the greater the malleability and ductility, as well as the final strength and elongation of the alloy. This is in opposition to usual metallurgical thinking where ductility increases as grain size increases (Guy, 1960).

This subject of grain size control has not received adequate attention by those interested in developing improved dental metallic products, and this offers an excellent research problem in dental metallurgy.
Ryge (1958), Peyton et al (1964) & Anderson (1967) all demonstrated that grain growth will occur if excessive or prolonged heating is applied to the metallic structures during soldering operation.

The degree of grain growth is primarily related not only to the alloy composition and mechanical treatment received during fabrication but also to the temperature applied below the melting point of the metal and the duration of the heating operation. It is found that high temperature or long heating periods produce the greatest amount of grain growth. It is, therefore, common to find that during a soldering or annealing operation, the temperature applied to the metal or alloy is sufficiently high to cause grain growth.

Gabel et al (1961) pointed out that any heating operation which requires heating above 300°F should be considered as a potential heat-treating operation.

Generally grain growth occurs more readily in wrought structures than in cast structures. This readiness is undoubtedly related to the tendency for metals to maintain a crystalline internal orientation of the component atoms.

Grain growth results in a general weakening of the metallic structure. There are fewer grains, there is more chance for slip, and as a result the strength, hardness, are decreased but ductility is increased.
Since the physical and mechanical properties are usually reduced in structures that have grain growth, it is therefore necessary to guard against this excessive and prolonged heating. This tendency of grain growth must be kept to a minimum by keeping the time and temperature of heating as short and low as possible.

The phenomenon of grain growth occurs as a type of boundary migration by diffusion where one grain absorbs others. The cause of grain growth may be related to the surface energy of the grains which always tends to become a minimum. Consequently, any decrease in the number of grains will result in a decrease in surface energy. The ultimate growth would be the formation of one huge grain but grain growth does not normally progress to this extreme under practical conditions.
PROPERTIES OF GOLD SOLDER.

A survey of the dental literature shows that gold solders for dental use have apparently been given less attention than any other type of gold alloy used in dentistry.

Taylor and Teamer (1949) listed the following as the physical characteristics generally considered desirable in dental solders:

(1) Easy flowing,
(2) Free flowing,
(3) Freedom from pitting,
(4) Strength approximating or exceeding that of the underlying structure,
(5) Colour to match the materials with which they are used,
(6) Building qualities which permit the development of desired shapes by partial fusion,
(7) Freedom from corrosion or staining in service.

They also developed a series of practical soldering test methods to determine their properties and tabled a suggested requirements for dental gold solders ranging in fineness from .435 to .800 as a basis for purchase specifications.

The composition of the gold solder should be such that it will flow freely once it is melted. This is related to its
fluidity and surface tension as well as its ability to alloy superficially with the work to be soldered.

The quality of a soldered joint is influenced by the degree of wetting of solid metal by the molten solder. The solder must wet the materials to be joined before bonding occurs. Wetting is also necessary before the solder will flow into small spaces by capillary action. The degree of wetting is determined by the interfacial energies between the solid metal and the molten solder and by the surrounding medium such as flux.

As mentioned by Skinner and Phillips (1967) the flowing property and a physical adhesion of the solder to the metal are extremely important. Without true adhesion there is no actual soldering action, but only a mechanical anchorage to surface irregularities. The molten solder physically adheres when it leaves a continuous permanent film on the surface of the alloy instead of merely rolling over it. For such adhesion to occur, there must be a strong attraction between the atoms of the liquid solder and those of the metal surface than between the atoms of the solder itself.

Easy flowing quality refers to the fusion temperature, and the lower the temperature of fusion, the easier it is to melt and form the joint. In general, the lower the melting temperature of the alloys being soldered, the lower should be
the fusion temperature of the solder employed. The lower-fineness solders are more fluid in the molten state than are the high-fineness solders due to the lower gold content and presence of such alloying metals as Zn, Sn. Lower-fineness solders are to be preferred when parts are to be joined because the solder flows promptly and freely into the available spaces.

The solder should not cause pitting of the joint. Pitting seems to be more closely associated with improper technique due to overheating and use of excessive amount of flux.

Ryge (1958) related pitting of the solder to the small gap distance between the parts to be soldered.

The strength of gold solders is important in that soldered joints are often small in proportion to the size of other portions of the dental restoration and must carry considerable stress. The hardness and strength of gold solder increases as the gold content decreases. Gold solders of lower carat than the parts to be soldered are generally used. They are normally harder and stronger, and the user seldom needs to consider strength in selecting a solder for use.

Taylor and Teamer (1949) maintained that gold solders above .650 fine should not be used when considerable stress is involved.

Anderson (1967) mentioned that the strength of a soldered joint may be greater than that of the solder itself.
This is due to a change in the composition of the solder by virtue of a slight alloying between it and the surface of the metals being soldered.

The colour of dental gold solders varies from deep yellow to light yellow and white. Colour was often mentioned as an important property of gold solder but, in practice, the colour of the soldered joint after polishing is usually not noticeable even though there may be considerable difference in colour between the solder and the work.

Crawford (1948) suggested gold solder of .580 fineness as the minimum fineness for permanent use in the mouth. Souder and Paffenberger (1942), Spreng (1940), however, stressed that probably a gold solder of at least .680 fineness is safer so far as the prevention of discoloration is concerned.

Building ability of the gold solder depends not only fundamentally on its basic composition and the width of its fusion range, but to a greater extent upon the proper control of the soldering flame by the operator.

It is often suggested that the highest fineness solder possible should be employed to prevent tarnish and corrosion in service. However, lower fineness solders are employed extensively for assembly of dental appliances without serious tendencies to discoloration.

Peyton et al (1964) pointed out that no one dental
gold solder will meet all the qualities, and for this reason manufacturers make available solders covering a range of fineness as well as providing a number of solders with special qualities. The behaviour of solders is influenced significantly also by the method of use during the soldering operation, which makes it imperative that a recommended procedure be followed faithfully if the maximum in quality is to be obtained from any given product.

Gold solders for dental use are primarily alloys of gold, silver and copper with small quantities of Sn, Zn and perhaps phosphorous included to modify the fusion temperature and flow qualities.

Coleman (1928) tabled the composition of dental gold solders as follows:

<table>
<thead>
<tr>
<th>Solder No.</th>
<th>Gold (%)</th>
<th>Silver (%)</th>
<th>Copper (%)</th>
<th>Zinc (%)</th>
<th>Tin (%)</th>
<th>Fusion Temp. °F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>65.4</td>
<td>15.4</td>
<td>12.4</td>
<td>3.9</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>66.1</td>
<td>12.4</td>
<td>16.4</td>
<td>3.4</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>65.0</td>
<td>16.3</td>
<td>13.1</td>
<td>3.9</td>
<td>1.7</td>
<td>1470</td>
</tr>
<tr>
<td>D</td>
<td>72.9</td>
<td>12.1</td>
<td>10.0</td>
<td>3.0</td>
<td>2.0</td>
<td>1535</td>
</tr>
<tr>
<td>E</td>
<td>80.9</td>
<td>8.1</td>
<td>6.8</td>
<td>2.1</td>
<td>2.0</td>
<td>1595</td>
</tr>
</tbody>
</table>
The A.S.M. Metal Handbook (1948) added two low gold content dental gold solders whose compositions are:

<table>
<thead>
<tr>
<th>Solder</th>
<th>Au</th>
<th>Ag</th>
<th>Cu</th>
<th>Zn</th>
<th>Sn</th>
<th>Fusion Temp. °F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.5</td>
<td>30-35</td>
<td>15-20</td>
<td>2-4</td>
<td>2-3</td>
<td>1276-1501</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>12-32</td>
<td>12-22</td>
<td>2-4</td>
<td>2-3</td>
<td>1335-1535</td>
</tr>
</tbody>
</table>

Relatively little information is available in the dental literature on the mechanical properties of gold solder. Coleman (1928) again tabulated the typical mechanical properties as follows:

<table>
<thead>
<tr>
<th>Solder No.</th>
<th>Heat Treatment</th>
<th>Proportional Limit, (p.s.i.)</th>
<th>Tensile Strength, (p.s.i.)</th>
<th>Elongation (%)</th>
<th>B.H.N.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Softened</td>
<td>27,000</td>
<td>43,500</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hardened</td>
<td>55,000</td>
<td>63,000</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Softened</td>
<td>29,500</td>
<td>44,500</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hardened</td>
<td>77,500</td>
<td>83,500</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Softened</td>
<td>30,000</td>
<td>44,000</td>
<td>9</td>
<td>111</td>
</tr>
<tr>
<td></td>
<td>Hardened</td>
<td>77,000</td>
<td>92,000</td>
<td>1</td>
<td>199</td>
</tr>
<tr>
<td>D</td>
<td>Softened</td>
<td>24,000</td>
<td>36,000</td>
<td>7</td>
<td>103</td>
</tr>
<tr>
<td></td>
<td>Hardened</td>
<td>61,500</td>
<td>70,000</td>
<td>1</td>
<td>180</td>
</tr>
<tr>
<td>E</td>
<td>Softened</td>
<td>20,500</td>
<td>37,500</td>
<td>18</td>
<td>78</td>
</tr>
</tbody>
</table>
The heat treatment designated as "softened" consisted of quenching the alloy in water from a temperature of 700°C. (1292°F.) and when the alloy was "hardened", it was age hardened by cooling it slowly from 450°C to 250°C.

The proportional limits and tensile strengths of the gold solders are comparable in value to the similar properties of a type B or C casting gold alloy.

The values for the elongation of the gold solders are definitely lower than those of any of the other types of gold alloys. This leads to the tendency for the solders to be more brittle especially after heat treatment.

The gold solders are generally amenable to age hardening, although solder E (Coleman's table) is an exception. Solder E has a Cu content of 6.8 per cent.

In general, the hardness of solders increases as the fineness is decreased. Peyton et al. (1964) mentioned that dental gold solders are used normally on gold alloys of higher fineness than the solder. The strength of the solder is approximately equal to that of the alloy on which the solder is applied.
ONE PIECE CASTING.

In its application to dentistry soldering has assumed the significance of an art of much greater importance than ever attained by the goldsmiths or silversmiths. However, when the restorations are assembled, they frequently fail to go into place, though the individual abutments can fit exactly. The failure to do so is mainly the result of distortion and consequent loss of relationship between the various parts during the investing and soldering procedures.

Since the distortion of soldered fixed partial dentures could not be completely eliminated even with sufficient gap distances as suggested by many investigators, Tylman (1954) advocated that the pontics be soldered separately to the individual abutments and the two parts soldered in only one spot to complete a fixed partial denture with the purpose of minimizing the warpage due to soldering at the final stage.

On the other hand, techniques of one piece casting bridge have been developed. Today, castings of extreme accuracy can be made for the abutment teeth with our present casting techniques. Suffert and Mehler (1955) reported that the variations in dimension of castings made by present casting techniques may be in the order of 1.0 per cent. Fusayama (1959) however, stressed that such a large variation might be due to faulty techniques, such as the pour-moulding of inlay wax, the
use of boiling water for eliminating wax from the mould and the direct measurement of small castings under a microscope. Skinner (1954) stated that the minimum deviation may be approximately 0.1 per cent. Fusayama (1959) obtained a standard deviation of less than 0.05 per cent in his investigation.

Much research has been performed on one piece casting for fixed prostheses. Bruno (1955) used transfer copings and wax patterns for one piece bridge castings. Rubin and Sebella (1955) used one piece wax patterns from dies for small (3-unit) bridges but used a duplicate model of refractory casting investment for larger bridges. Penser (1953) used resin patterns for one piece fixed bridges without soldering procedures. Leff (1953) stated that some of his temporary acrylic bridges have been cast in gold in experimental attempt to eliminate the necessity for the soldering of fixed bridgework. Tamarin (1961) employed one-piece casting for multiple pontic only and joined this unit to the abutment attachments by soldering. This one-piece casting of multiple backing eliminates the grinding, fitting, aligning and soldering of the several backings into one unit. Fusayama (1959) developed a technique of one piece cast bridge or splint utilizing an improved thermal expansion technique.

Fusayama, Wakahoto and Hosoda (1964) studied the degree of accuracy of bridgework made by varying soldering techniques, and by one-piece casting techniques. They concluded that,
although fewer errors were produced by reducing the number of areas soldered in the final step, the greatest accuracy was produced in fixed partial dentures produced by one-piece castings using the improved thermal expansion technique. The soldered bridges were generally undersized in the mesio-distal dimension and the one-piece cast bridges were generally slightly oversized.

Bruce (1964) made evaluation of the accuracy of multiple unit castings for fixed partial dentures and concluded that changes in the castings from the patterns to the cast product depend on the refractory investment, expansion, pattern material and the method of spruing the pattern in the mould. One-piece castings shorter than 15.5 mm. in length were accurate in length and abutment fit and no changes occurred in the fit of abutment crowns regardless of form of casting. Those one-piece castings over 15.5 mm. in length showed a slight contraction. With proper fabrication and spruing of patterns, one-piece fixed partial denture castings can be accurately made.

All these investigators are trying to eliminate or minimize the procedures of soldering which sometimes introduce certain inaccuracies and imperfections that would be vexing and discouraging.

No effort was made by Bruce (1964) to evaluate a solder joint versus a cast joint. However, he stressed that either
solder or cast joints should be clinically acceptable provided that they are of proper shape and are free of porosity.

Dykema (1961) made a study of the effects of certain variables on the comparable strengths of soldered and cast bridge joints.

Gabel et al (1954) mentioned that when one-piece castings are used, no attention to the heat treating effects of soldering is necessary and heat treatment may be accomplished most conveniently during cooling from casting. One-piece castings, however successful they may be in some well selected cases, do not meet the widest range of needs of dentistry. It would be distinctly narrowing to the service which dentistry might render.
FIT OF SOLDERED CONSTRUCTIONS.

Dental restorations are used to restore lost functions as well as to prevent further loss of function. In order to attain these objectives, the dental restorative procedures must be exact. The highest degree of accuracy is required in the field of bridgework. Precision casting techniques have been developed which can give very accurate results. Even so, the abutments can fit exactly and the soldered bridge fail to go into place properly because of distortion resulting from the soldering procedure.

Ante (1918) pointed out that the shrinkage of gold solder increases in proportion to the quantity of base metals incorporated. Thus, the lower the carat, the more shrinkage. In extensive work shrinkage may be minimized by soldering the parts separately, then in the final assembly of these parts very little solder is used to secure union and strength. Very large bridges should be divided and soldered in sections, the sections being subsequently united. The change in the relation of the parts caused other than by shrinkage or carelessness in investing was rare.

- Steinman (1954) studied the warpage produced by soldering and concluded that: (i) the less solder used, the less distortion produced, (ii) bench cooling a soldered joint produces
less distortion than plunging. Plunging an invested joint produces significant distortion, (iii) reheating and plunging or reheating and bench cooling can produce significant changes in a soldered piece of work and (iv) the more exact the fit of the parts to be joined, the less will be the distortion produced.

Anderson, Fairhurst and Ryge (1958) studied the dimensional changes in gold soldered junctions. They demonstrated that if the parts to be soldered are in contact before heating, warpage will occur. In the investment soldering procedure, the gap closes up 0.002" to 0.004" during preheating to 1100°F., and if the solder gap is narrower than this, warpage occurs.

Ryge (1958) stressed the importance of providing sufficient gap distance (approximately 0.005" minimum) to prevent warpage during heating and investing in a controlled soldering investment.

Perdigon and Van Bepoel (1957) & Kowalewski (1958) all pointed out that the exact cause of distortion of fixed and removable partial dentures during soldering procedures is difficult to determine. Kowalewski (1958) mentioned that there is no one method which completely eliminates all possibility of distortion. Fortunately, distortion does not occur consistently, but it does happen occasionally. It appears also that distortion can occur in three stages. It can occur before
soldering, then during soldering and finally after soldering. All of the factors which might cause distortion at each stage must be considered in order to eliminate or minimize distortion.

Myer (1959) agreed that distortion can take place in the soldered joint or in the handling of the investment or in both. He suggested a uniform preheating of the invested block in a porcelain furnace and this will eliminate the errors which result from uneven blowpipe or bunsen burner preheating.

O'Brien (1960) pointed out that because a casting will expand during heating, it is necessary to provide for this expansion when preparing the joint for soldering. Otherwise, distortion will occur. To compensate for this expansion, it is necessary to maintain a gap distance of at least 0.01".

Hollenback, Smith and Shell (1966) found that the shape of the joint apparently had no appreciable effect on distortion but the width of the soldered joint has a marked effect on distortion, particularly if the joint width is too narrow or if direct contact occurs. This condition is caused by the change in the dimension of gold pushing or pulling the joints during the soldering operation.

All these investigators have stressed the importance of gap distance and uniform preheating for investment soldering to prevent the possible change in the relation of the parts which would interfere with the fit and adaptation of the soldered work.
MICROSTRUCTURE OF THE SOLDERED JOINT.

Much has been written on how to obtain a good, strong soldered joint, but little attention has been paid to the actual microscopic structure of these joints.

The science of metallography deals with the investigation and study of the internal structure of metals and alloys. The investigation of precious metals or alloys is fairly undeveloped in the science of metallography.

Microscopic examination of well formed soldered junctions has revealed that the gold solder does not combine excessively with the parts being soldered. Peyton et al (1964) mentioned that, when the solder has melted properly and not been overheated, there should be a well defined boundary between the solder and the soldered parts. Once the heating operation is prolonged, the excessive heating will cause a noticeable diffusion between the solder with the parent metals. The amount of diffusion is in direct proportion to the time and temperature of overheating.

Ryge (1958) studied the proper soldering temperature for the 18K gold solder employed and demonstrated the metallographic structure of the properly and improperly soldered joints.

He concluded that, as the soldering temperature increases, the atomic diffusion continues till the solder and the
parent alloy completely fuse. The composition of both the solder and the parent alloy has been changed with the result that the physical properties of the joint are no longer under the control of the operator. Not only is the soldered construction weakened and embrittled by the overheating but distortion of the soldered work also results.

Skinner and Phillips (1967) stressed that the same effect of atomic diffusion can occur at lower temperatures, though not as readily, if the heating is sufficiently prolonged. They suggested that the soldering should be accomplished at the lowest temperature and in the least time possible.

Ryge (1958) also demonstrated the amount of porosity in the soldered joints upon microscopic examination. He found that porosity occurred much more frequently with small gap distances, and when soldering with parts in contact, the solder would not flow through the contact area though the joint was satisfactory macroscopically.

Coleman (1928) showed that the grains in the soldered part may act as nuclei of crystallization for the solder.

Peyton et al (1964) also showed, properly and improperly, soldered joints formed between cast gold alloys and gold wires as well as evidence of recrystallization due to excessive heating operation which results in breakage during service.
Shell (1962) showed an almost perfect unetched soldered joint with only a few small pits in the solder and two pits in the parent metal.

O'Brien, Hirthe and Ryge (1963) showed a photomicrograph of a solder-alloy interface when discussing the wetting characteristic of dental gold solders.

El-Genishi et al (1968) studied the soldered joint under the electron microscope. They showed the effect of overheating in soldering. They claimed that overheating produces undesirable, diffusion along grain boundaries. Greater microporosity was also observed in overheated soldered joints.
POROSITY IN CASTING.

A study of the structure of the dental gold alloys has as its purpose the further refinement of the dental casting and soldering procedures which are essentially a metallurgical operation. It is becoming increasingly evident that the casting and soldering operation must be guided by some knowledge of the fundamental principles of metallurgy if uniformly successful results are to be expected. It is actually a study at close range of the metal's or alloy's physical and structural constitution. It deals with the minute units of alloy known as the grains or crystals and their intercrystalline spaces. It studies the relation of these grains and their habits to the physical and mechanical properties of the metals and alloys. They all have their basis in the condition of the component grains of which they are made up and the cohesion between the bonding surfaces of such grains.

Thompson (1924), Peyton (1934), Crawford (1940) & Coleman (1947) all pointed out the significance of porosity or void for physical properties of dental casting golds.

Shell (1923) mentioned that, from a purely metallurgical standpoint, an inlay should be composed of a metal which is homogeneous, capable of forming a smooth casting and free from pits or imperfections. He also pointed out (1931) that the presence of
microscopic pits in many inlay castings may be due to the forcing of entrapped air into the molten gold.

Various types of internal porosities have been recognized, classified and studied. They are:

1. Localized shrinkage porosity (Ryge, Kozak and Fairhurst, 1957).
7. Pin hole porosity (Ryge, Kozak and Fairhurst, 1957).
8. Porosity due to presence of foreign body.

(1), (3), (4) types of porosities in gold castings are caused by cooling and solidification of the molten gold alloys.

(2), (7) types of porosities are caused by gas.

(5) is the result of incomplete burn out, and the porosities extend only about 0.01 inches below the surface of casting.

(6) is due to lack of rapid venting for the hot gases in the mould cavity during casting.

Ryge, Kozak and Fairhurst (1957) studied some of the variables which might contribute to porosities in dental gold castings. They studied the porosities caused by cooling and solid-
ification as well as those caused by gas.

They tabulated the effect of various technical factors on the porosities resulting from the solidification of the alloy as follows:

<table>
<thead>
<tr>
<th>Type of Porosity</th>
<th>Increased Sprue Thickness</th>
<th>Increased Sprue Length</th>
<th>Increased Alloy Temperature</th>
<th>Increased Mould Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localized Shrinkage</td>
<td>Decreased</td>
<td>Increased</td>
<td>Decreased</td>
<td>Decreased</td>
</tr>
<tr>
<td>Subsurface Porosity</td>
<td>Increased</td>
<td>Decreased</td>
<td>Increased</td>
<td>Increased</td>
</tr>
<tr>
<td>Microporosity</td>
<td>No effect</td>
<td>No effect</td>
<td>Decreased</td>
<td>Decreased</td>
</tr>
</tbody>
</table>

For porosities caused by the gas, Ryge, Kozak and Fairhurst (1957) found that pinhole porosity occurred when the alloy was cast at a very high temperature (more than 200°F above the melting range). No relationship was established between sprue size and pinhole porosity. Gas inclusions were found when the alloy was cast at very low temperatures, within or slightly above the melting range. No relationship was established between sprue size and gas inclusions.

Skinner and Phillips (1967) pointed out that all the porosities caused by cooling and solidification of the alloy can be minimized by controlling the rate at which the molten metal enters the mould.
They also pointed out that the pinhole and gas inclusion porosities are both related to the entrapment of gas during solidification. They are characterized by a spherical contour. Many metals dissolve or occlude gases while they are in the molten stage. Copper and silver dissolve oxygen in large amounts in the liquid state, while molten Pt., Pd., have a strong affinity for \( \text{H}_2 \) and \( \text{O}_2 \). Upon solidification, these absorbed gases are expelled and porosities result.

These porosities may also be caused by gas mechanically entrapped by the molten metal in the mould or carried in during the casting procedure, as suggested by Shell (1931).

Skinner and Phillips (1967), Coleman (1928), Sausen and Serr (1958), Ryge, Kozak and Fairhurst (1957) & Keys (1945) all suggested the use of an adequate size sprue or use of a reservoir close to the casting will minimize the chance of localized shrinkage porosity.

Ryge, Kozak and Fairhurst (1957) & O'Brien (1969) pointed out that an increase in sprue length will lead to an increase in localized shrinkage porosity.

Skinner and Phillips (1967) illustrated localized shrinkage porosity caused by an improper sprue angle which caused turbulence of the entering molten alloy.

Microporosity is occasioned by underheating the metal or alloy prior to casting. Temperature of metal should be \( 38^\circ \)
to 50° C (100° to 150° F) above its liquidus temperature when the casting is made, as suggested by Ryge, Kozak and Fairhurst (1957).

Subsurface porosity produced by the bulk of the molten gold alloy pulling away from the "skin" portion first to solidify, can be largely prevented by not overheating either the melt or the investment mould. Thus a more uniform solidification of the molten metal tends to occur.

Water vapour porosity is prevented by the complete burn out of the wax in the mould.

Back pressure porosity can be avoided by the use of a sprue long enough so that the outer end of the casting is within 6 mm. (1/4 in.) of the open end of the ring, the use of sufficient casting pressure and flaring the sprue at the point of attachment to the wax pattern.

Porosity due to foreign bodies such as flux, pieces of investment or bits of carbon from the flux, can be avoided by the careful use of flux, not too high a mould temperature which will break down the investment, and by handling all casting moulds with the sprue hole downwards.
METHODS OF CASTING.

The science and art of casting is one of the oldest. Casting is probably the most primitive method of metal work. The so-called "modern dental casting" processes are by no means new. The methods that we are now so eager to learn were handled by the Old Masters in the founding art with satisfactory results. This is especially true of the "Circe Perdue", Dis-appearing model" or "Wasting wax" process.

The earliest account of the casting by Circe Perdue process is given in Knight's American Mechanical Dictionary as 2230 B.C., and has to do with a reference by Herodotus and Diodorus to massive bronze statues that were set up in the Temple of Belus in Babylon.

This also is true of the method for forcing the metal into the mould in common use today. The force necessary to drive the molten metal into the mould may be applied in three different ways. They are:-

1. Air pressure,
2. Steam or Gaseous pressure,
3. Centrifugal force.

Pressure casting, as it is usually called, has now passed far beyond what may be termed its first experimental stage and a large literature has grown up around it. Much
scientific investigation has been made into the physical properties of the materials used for casting.

Casting machines are used for the actual casting process. All casting equipment consists of a device for melting the metal and another for throwing it quickly into the mould cavity. The most popular method of melting the metal is by using a gas-air blowtorch. A properly adjusted blowtorch will develop a temperature which is adequate for melting dental gold alloys whose melting range is between 1600°F and 1900°F. Much depends upon the proper adjustment of the blowtorch flame to complete the melting operation. A poorly adjusted flame can be a nuisance by not only wasting time but by causing considerable damage to the gold alloy being heated, through excessive oxidation or gas inclusion.

The centrifugal gas-air casting machine and the gas-air hand swinger are the most commonly used casting devices, though a number of the older type air pressure casting machines are still in use which usually require a 10 lb. per sq. in. gauge pressure.

The advantage of the centrifugal casting is that the casting force is constant for a given mass of molten alloy. Also the casting force is applied directly to the molten alloy and cannot be dissipated as in the case of air or steam pressure.
A large variety of machines has been developed to make dental castings. These casting machines can be divided into two general types:

1. Gaseous pressure casting using air or steam,
2. Centrifugal casting which can be subdivided into (a) centrifugal gas-air casting,
   (b) centrifugal electric casting,
   (c) hand swinger casting.

The air or steam pressure method of casting has several apparent disadvantages. Firstly, the blast of air cools the molten alloy slightly and increases its viscosity. When using steam pressure, the pad of wet asbestos may even contact the molten alloy and so chill it. Also, the gaseous pressure is not applied to the molten alloy entirely because of the difficulty of getting a perfect seal at the top of the crucible.

The Jelenko-Thermotrol casting machine combines the melting and casting functions into one piece of equipment. The metal is melted within a carbon crucible electrically, and centrifugal force is used to complete the casting. Many undesirable variables due to human skill which can affect casting are eliminated by the use of this type of casting machine, and more uniform results of casting can be obtained this way. Peyton et al (1964), however, pointed out that many of these electric heating units have no limiting controls and as a result the
operator is required to display judgment regarding the proper
condition of the alloy to cast. Some electric units required
slightly longer time to complete the heating and casting
operation than is necessary when blowtorch melting is employed.

Skinner and Phillips (1967) remarked that there is
little difference in the physical properties or accuracy of the
castings obtained with any type of casting machine, and the
choice between the various types is a matter of personal
preference. In fact, any method, by which the molten alloy
can be forced into the mould under sufficient pressure so that
the pressure can be maintained for at least four seconds after
the metal has been cast, is satisfactory.
TYPES OF GOLD.

Gold is amongst the oldest of the restorative materials used in dentistry. Early records indicate that gold was used as early as the first century of the Christian Era by the Romans to replace lost tooth structure. How long it had been used before that time and how common was the use of gold as a restorative material is not well known.

Very soft inlay gold with B.H.N. under 85 (24K, 22K, gold coins) were for the most part popular when the inlay casting process was first developed. These were very difficult to cast free from blow holes and occluded gases. The materials were so soft and ductile that castings could be easily cold worked by swaging and burnishing. Fitting of the gold castings to the cavities or preparations was not a problem. This capability of moderate cold working probably accounts for some of the success of the malleted gold restorations.

Mechanical properties of 24K, 22K, and Coin Gold,

(adapted from Peyton et al, 1964, p.308).

<table>
<thead>
<tr>
<th></th>
<th>Tensile Strength</th>
<th>Prop. Limit</th>
<th>Elongation</th>
<th>B.H.N.</th>
</tr>
</thead>
<tbody>
<tr>
<td>24K</td>
<td>15,000</td>
<td>1,500</td>
<td>30</td>
<td>24</td>
</tr>
<tr>
<td>22K</td>
<td>35,000</td>
<td>12,000</td>
<td>22</td>
<td>54</td>
</tr>
<tr>
<td>Coin Gold</td>
<td>57,500</td>
<td>22,500</td>
<td>30</td>
<td>85</td>
</tr>
</tbody>
</table>
42.

As a result of the comparisons of the mechanical properties of gold and its alloys, the use of the very soft gold for inlays has been largely discarded and the alloys of gold substituted for them. The reason given is that the 24K, 22K and gold coins did not possess properties that were adequate for the more complex cast restorations such as fixed or removable bridge structures.

Accordingly there has developed during the intervening years the different types of gold alloys which possess properties that make them appropriate for specific types of dental restorations.

The dental gold alloys now available for casting generally are grouped into four types, each having slightly different properties. Besides gold, these alloys are made up of silver, copper, platinum, palladium, zinc and sometimes nickel in quantities varying from small fractions of one per cent to ten per cent or 16 per cent, with the gold content varying between 60 per cent and 92.5 per cent.

The compositions of the four types of dental gold alloys is tabulated as follows:
<table>
<thead>
<tr>
<th>Type</th>
<th>Gold (%)</th>
<th>Silver (%)</th>
<th>Copper (%)</th>
<th>Palladium (%)</th>
<th>Platinum (%)</th>
<th>Zinc (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(I)</td>
<td>79-92.5</td>
<td>3-12</td>
<td>2-4.5</td>
<td>0-0.5</td>
<td>0-0.5</td>
<td>0-0.5</td>
</tr>
<tr>
<td>B(II)</td>
<td>75-78</td>
<td>12-14.5</td>
<td>7-10</td>
<td>1-4</td>
<td>0-1</td>
<td>0.5</td>
</tr>
<tr>
<td>C(III)</td>
<td>62-78</td>
<td>8-26</td>
<td>8-14</td>
<td>2-4</td>
<td>0-3</td>
<td>1</td>
</tr>
<tr>
<td>D(IV)</td>
<td>60-71.5</td>
<td>4.5-20</td>
<td>11-16</td>
<td>0-5</td>
<td>0-3.5</td>
<td>1-2</td>
</tr>
</tbody>
</table>


Souder and Paffenbarger (1942) classified the dental casting gold alloys according to their composition as it affects their surface hardness.

<table>
<thead>
<tr>
<th>Type</th>
<th>B.H.N. (Softened Condition)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>I (A)</td>
<td>40</td>
</tr>
<tr>
<td>II (B)</td>
<td>70</td>
</tr>
<tr>
<td>III (C)</td>
<td>90</td>
</tr>
<tr>
<td>IV (D)</td>
<td>130</td>
</tr>
</tbody>
</table>

These four types of casting gold alloys have been developed to possess definite properties which make them suitable for specific types of restorations. Hence, their classification can be based according to their use as suggested by Skinner and Phillips (1967).
In general, the soft, quite ductile Type A (I) alloys are limited to use in inlays which are subject only to slight stress during mastication such as the restorations of Black's Class III and V cavities. Type A alloys correspond in general with those of the 22K soft gold.

Type B (II) gold alloys have a B.H.N. of 70 - 100. This type may contain some Pd. and Pt. and the Cu. content is higher than that of type A gold alloy. According to the amount of Cu content, these alloys are classified as "light" and "dark". Fusion temperature is lower than type A. The ability to be cold worked readily and adapted with hand instruments is not so great as with Type A alloys perhaps because of the slightly greater hardness and proportional limit rather than because of low values of elongation. Type B alloys can be used for practically all types of cast inlays and they are very popular with the dental profession for operative procedures.

Type C (III) alloys have a B.H.N. of 90 - 140 in the softened condition. These alloys generally respond to heat treatment during the casting and cooling operation or during subsequent heating while soldering. Type C alloys are most acceptable for crowns and bridge abutments which are subject to great stress in the mouth. On age hardening, there is a marked decrease in ductility with a slight increase in hardness.
Type D (IV) alloys are extra hard with B.H.N. of over 130 in the softened condition. These alloys are designed to have sufficient strength and adequate properties for cast denture work. Properties of elongation and proportional limit are changed significantly during the age hardening procedure and the B.H.N. can be increased to over 220. Type D (IV) alloys are not used in fixed restorations because of their high tarnish and corrosion potential.

<table>
<thead>
<tr>
<th>TYPE</th>
<th>TREATMENT</th>
<th>B.H.N.</th>
<th>ULTIMATE TENSILE STRENGTH (100 Kg/Cm²)</th>
<th>ULTIMATE TENSILE STRENGTH (1000 lb/in²)</th>
<th>PROPORTIONAL LIMIT (100 Kg/Cm²)</th>
<th>PROPORTIONAL LIMIT (1000 lb/in²)</th>
<th>ELONGATION (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(I)</td>
<td>Softened</td>
<td>45-70</td>
<td>21-32</td>
<td>39-45</td>
<td>6-10</td>
<td>8-15</td>
<td>20-35</td>
</tr>
<tr>
<td>C(III)</td>
<td>Softened</td>
<td>95-115</td>
<td>34-40</td>
<td>48-57</td>
<td>16-21</td>
<td>23-30</td>
<td>20-25</td>
</tr>
<tr>
<td></td>
<td>Age hardened</td>
<td>115-165</td>
<td>42-57</td>
<td>60-82</td>
<td>20-41</td>
<td>29-58</td>
<td>6-20</td>
</tr>
<tr>
<td>D(IV)</td>
<td>Softened</td>
<td>130-160</td>
<td>42-52</td>
<td>60-75</td>
<td>24-33</td>
<td>35-47</td>
<td>4-25</td>
</tr>
<tr>
<td></td>
<td>Age hardened</td>
<td>210-235</td>
<td>70-84</td>
<td>100-120</td>
<td>42-64</td>
<td>60-92</td>
<td>1-6</td>
</tr>
</tbody>
</table>

Regardless of the terms employed to describe the above four major types of casting gold alloys, it should be recognized that the hardness and strength qualities differ from one group to another, which makes one type more suitable than another for certain specific restorations. Most manufacturers produce more than one alloy in each of the four types, so that a range of qualities is available and these products generally comply with the requirements of the various dental association specifications.
HEAT TREATMENT OF GOLD ALLOYS.

Paillard (1886), Kunaknow, Zemczuzny and Zasadzelsky (1916) are generally given credit for first observing the influence of heat treatment on gold alloys. These investigators found the two compounds AuCu$_3$ and AuCu were formed from the solid solution during solidification of the gold alloys if the temperature was held below about 425$^\circ$C (797$^\circ$F). It was observed that time was required for the transformation to occur from the solid solution and also that the solid solution phase was retained if the alloy was quenched from the temperatures above that of compound formation. Slow cooling to room temperature or heating at the lower temperatures permitted the compound to form. The solid solution was relatively soft and malleable but the alloy became hard and brittle when the compound was formed. Thus the basis for the practice of heat treating dental gold alloys was established.

Besides gold as the main constituent, dental gold alloys consist of as many as six other metals, the actual transformations which take place during heat treatments are complex. Very likely, the softening and hardening of the gold alloys may result from several different solid-solid transformations.
Copper is by far the most important constituent in the dental gold alloys. Its addition to gold not only increases the strength and hardness of the alloy, but also plays an important role in the hardening effect, upon heat treatment, in combination with gold, Pt, and Pd. More than 8 per cent of Cu must be present for an alloy to be amenable to heat treatment. Lane (1949) reported that, if eight to as high as 25 per cent Cu is present, age hardening occurs readily.

Only certain dental alloys are subject to hardening and softening as a result of the controlled application of heat to the alloy during and subsequent to the casting operation. This characteristic of changing of properties due to heat treatment applies mainly to Type C (III), Type D (IV) casting gold, gold solders and gold wires.

When these gold-copper alloys are cooled slowly from above 450°C, taking about ½ hour to reach room temperature, the Au and Cu atoms diffuse within the solid metal and form one of the two super-lattices. In alloys containing between 40 and 65 wt. per cent of gold, a face-centred cubic super-lattice based on Au$_{0.5}$Cu is formed. From 65 to 87 wt. per cent of gold, a tetragonal super-lattice of Au$_{0.5}$Cu is formed. Since all gold alloys must contain at least 75 per cent of Au to resist corrosion and tarnish in the mouth, this ordered structure of Au$_{0.5}$Cu is the one of dental importance. This Au$_{0.5}$Cu super-lattice
is also of different dimensions from the normal lattice, thus limiting the movements of dislocations and reducing slip. This, combined with an increased attraction between atoms associated with ordering, improves the hardness, strength and proportional limit of the alloy while reducing its ductility.

<table>
<thead>
<tr>
<th>METHODS</th>
<th>HARDNESS</th>
<th>TENSILE STRENGTH</th>
<th>PROPORTIONAL LIMIT</th>
<th>ELONGATION (DUCTILITY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softening</td>
<td>Decreased</td>
<td>Decreased</td>
<td>Decreased</td>
<td>Increased</td>
</tr>
<tr>
<td>Hardening</td>
<td>Increased</td>
<td>Increased</td>
<td>Increased</td>
<td>Decreased</td>
</tr>
</tbody>
</table>

**EFFECT OF HEAT TREATMENTS ON PROPERTIES OF GOLD ALLOYS.**

Those gold alloys which respond to heat treatments can be softened or hardened.

For softening heat treatment, the gold alloy is placed in an electric furnace for 10 minutes at a temperature of 700°C (1290°F) and then it is quenched in water. During that period, it is assumed that all solid transformations are changed to a disorder solid solution and the rapid cooling by quenching has actually prevented their re-formation upon cooling and thus "fixed" the properties of the alloy that were developed at the elevated temperature.
Hardening heat treatment can be achieved by any of the following described ways:

(i) Cooling of the gold alloy to room temperature from 700°C after it has been held at that temperature for 10 minutes.
(ii) Cooling of the gold alloy from 450°C (840°F) to 250°C (480°F) over a period of 15-30 minutes in an electric furnace, and then quench in water. This is the oven-cooling method.
(iii) Skinner and Phillips suggested the soaking of the gold alloy between 350°C (660°F) and 450°C (840°F) for 15 minutes before it is quenched. There seems to be little difference between this method and the oven-cooling method which may render the alloy too brittle, and is recommended for testing purposes only, by the American D.A. Specification.

The proper method of hardening a gold alloy is to follow the heat treatment direction specified by the manufacturer of that particular gold alloy.

Skinner and Phillips (1967) suggested that, in any event, before a dental gold alloy is given a hardening heat treatment, it should always be subject to softening heat treatment first in order to relieve all strain hardening, if present, and to start the hardening treatment with the alloy as a disordered solid solution. Otherwise, there would not be a proper control of the hardening process. The changes in mechanical properties are controlled by the amount of solid-solid transformations occurring which are in turn controlled by the temperature and time of the heat treatment.
Order-Disorder Reactions.

Order-disorder reactions form the basis for heat treatment in gold alloys.

An alloy is a mixture of two or more metals.

For dental purposes, the alloys can be classified on the basis of the solubility of the atoms in the solid state. The simplest alloy is one in which the atoms of the two metals intermingle randomly in a single space lattice. The grains of such an alloy may resemble those of the pure metals. The structure is entirely homogeneous. These metals are said to be soluble in each other and the alloys are called solid solutions.

Solid solutions may be of the substitutional or interstitial types. The substitutional solid solutions are more common in dental gold alloys. Alloys of gold with silver, platinum, palladium, copper, nickel and palladium with silver, form a series of substitutional solid solutions.

In a substitutional solid solution, if the atoms of the added metal take up positions at random in the parent lattice, then the solid solution is said to be disordered. In some alloys, solid solutions are disordered at higher temperatures, but undergo an atomic rearrangement on slow cooling of the alloys. Upon cooling, atoms of one kind segregate to one set of atomic positions leaving the other atoms to occupy the remaining sites.
and an ordered solid solution (super-lattice) is said to have developed.

Hardening heat treatment of alloys can be produced not only by precipitation but also by ordering of the solid solutions.

Wherever a solute atom displaces or substitutes for a solvent atom, the difference in size of the solute atom results in a localized distortion or strained condition of the lattice and whenever a lattice distortion occurs, slip becomes more difficult and the strength, proportional limit and hardness are increased, whereas the ductility is decreased. Consequently, the alloying of metals is a means of improving the mechanical strength of the metal.

In general, the hardness and strength of any metallic solvent are increased by the atoms of solute. The more nearly the atoms are of the same size, the less the effect of the strengthening of the alloy will be, but some increase in hardness and strength can be expected.

Generally, the more of the solute metal added to the solvent metal, the greater is the strength and hardness of the resulted alloy. In the case of two metals which form a continuous series of solid solutions with one another, the maximum hardness and strength will be reached at approximately 50 atomic per cent of each metal.
The ordered structure (super-lattice) which is produced by the slow cooling of the substitutional solid solution of the dental gold alloy, may have a space lattice similar to the disordered solid solution from which it forms or the atomic rearrangement may result in a change in the shape of the original space lattice. This change in shape will lead to a reduction in number of slip planes while the ordered arrangement is accomplished by an increased attraction between atoms. These effects combine to improve the mechanical strength of the alloy.

Alloying of gold with copper offers an excellent example of the order-disorder reactions. The disordered Cu-Au substitutional space lattice is a face-centred cubic while the ordered condition has a tetragonal super-lattice which is of different dimension from the normal lattice, thus limiting the movement of dislocation and reducing slip.

No order hardening occurs in AuCu₃ because of the lack of lattice straining - the smaller copper atoms easily fitting between the gold atoms.

Order-disorder reactions also occur in the Au-Pt and Au-Pd systems.

Order hardening may sometimes be more satisfactorily produced by quenching the disordered alloy from a high temperature to room temperature and so suppress the change initially. This disordered alloy can then be progressively ordered by heating at some predetermined temperature for a period of time.
- THE ORIGINAL INVESTIGATION -
THE SCOPE OF THE INVESTIGATION.

This investigation has been carried out of the effects of various common and popular casting methods, soldering techniques and heat treatments on dental casting gold alloys. Various methods of centrifugal casting have been used and the effect of these and the re-use of dental gold alloys have been evaluated. Single castings and one piece multiple castings have been made and compared.

Variables in soldering techniques investigated include gap size, type of fluxes, surface condition of the castings, electric and gas-air heating and contact point soldering.

The effects of these variables on the physical properties and structure of the parent alloys have been studied and evaluated.

The soldered castings have been subjected to study in the "as cast" state, after "softening heat treatment" and after "hardening heat treatment".

Observations of the microscopic structures of both unetched and etched specimens of the dental gold alloys and solder have been made. Hardness determinations, tensile tests, and bend tests have been carried out as a guide to the physical properties of the structure studied.
SPECIMEN PREPARATION.

Specimens have been prepared using five different casting gold alloys from two manufacturing sources. Table I (p. 57) lists these alloys and the gold solder used for all soldering operations. It was not considered necessary to investigate other types of gold alloys, as these should behave in a similar manner to the casting gold alloys investigated.

The types of specimens prepared were:

(i) Inlay castings prepared on a "Frasaco" model.
(ii) Two separate adjoining Class II inlays for subsequent soldering.
(iii) One piece castings of the two Class II inlays.
(iv) Cylindrical castings.
(v) Cast tension test specimens.
(vi) Cylindrical castings for bend tests.
(vii) Cylindrical castings for contact point soldering studies.

(i) Inlay Castings on a Frasaco Model.

Two adjoining Class I inlay cavities were prepared on premolar teeth on a "Frasaco" model.

Wax patterns were prepared for the two adjoining inlays by flowing blue inlay wax (S.S. White Regular Type II/Class II**)

* Franz Sachs & Co., Tettnang - Wuertt, West Germany.
into the cavities which had been lubricated with Kerr's "Microfilm". The wax patterns were carved and finished to correct anatomical form providing normal proximal contours and contact, using methods normally employed in indirect procedures.

In some instances the two patterns were invested individually for subsequent casting, finishing and soldering. Some patterns were waxed together before investing to provide a one piece pattern for a subsequent one piece casting to restore the two inlay cavities.

Wax patterns were sprued using 14 gauge hollow stainless steel sprues, and were invested using Kerr's Cristobalite in inlay rings, 1" diameter and 1 1/2" height, lined with asbestos, for castings made using a gas-air centrifugal casting machine, or a hand swinger. For castings made in a "Thermotrol" the same techniques of pattern formation and investing were employed, except that the size of the inlay ring was 1 1/2" diameter and 2" height.

All invested rings were allowed to set on the bench for at least 45 minutes before burnout and the thermal expansion technique was employed to compensate for casting shrinkages.

The rings were then placed in a low heat (200°C) furnace to pre-heat for 30 minutes before they were transferred

*** Kerr Manufacturing Co., Detroit, Michigan, U.S.A.

J.J. Jelenko Co., New Rochelle, New York, U.S.A.
## TABLE I.

<table>
<thead>
<tr>
<th>Type of Gold Alloy</th>
<th>Name</th>
<th>Melting Point</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I(A)</td>
<td>Precious Metal No. 1.</td>
<td>1000°C (1832°F)</td>
<td>Precious Metal Refining Co.*</td>
</tr>
<tr>
<td>Type II(B)</td>
<td>Precious Metal No. 2. Modulay</td>
<td>975°C (1790°F)</td>
<td>Precious Metal Refining Co.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>960°C (1760°F)</td>
<td>J.F. Jelenko Co.**</td>
</tr>
<tr>
<td>Type III(C)</td>
<td>Precious Metal No. 3. Firmiley</td>
<td>960°C (1760°F)</td>
<td>Precious Metal Refining Co.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>960°C (1760°F)</td>
<td>J.F. Jelenko Co.</td>
</tr>
<tr>
<td>Gold Solder</td>
<td>18K</td>
<td>750°C (1380°F)</td>
<td>Precious Metal Refining Co.</td>
</tr>
</tbody>
</table>

* Precious Metal Refining Co., Sydney, Australia.

** J.F. Jelenko Co., New Rochelle, N.Y., U.S.A.
to the high heat (600°C) furnace for a further 30 minutes after which they were ready to cast.

When using the gas-air centrifugal casting machine, the dental casting gold alloy was first melted with a gas-air blowtorch in a crucible and kept clean with borax powder flux. The reducing flame was used, and immediately alloy became molten, the heated inlay ring was transferred from the furnace to the casting machine next to the crucible. The actual casting was completed as quickly as possible, generally within 10 seconds.

For hand swinger casting, the heated ring was taken from the high heat furnace and placed into the bucket of the hand swinger. Casting gold alloy was then placed at the funnel formed by the crucible former of the ring. It was then melted with the reducing flame of the gas-air blowtorch. Borax powder flux was used to keep the molten metal clean and casting was completed by swinging which was maintained for at least five seconds.

For Thermodrol casting, the electrically controlled casting machine was pre-heated for approximately one hour before use. The temperature of the muffle was taken to the melting point of the dental casting alloy used. The alloy was then loaded into the carbon crucible and the temperature was taken a further 200°F above the melting point of the dental gold alloy.
After this, the pre-heated inlay ring was transferred from the high heat furnace and casting was completed within 10 seconds.

When the button of the casting turned black after casting, the inlay ring was taken from the casting machine or hand swinger, then it was plunged into cold water to remove the investment from the casting. The casting was then cleaned and pickled in 50 per cent $\text{H}_2\text{SO}_4$ in a test tube.

Polishing was completed using carborundum disks, sandpaper disks, rubber disks, tripoli, whiting and zinc oxide.

Most castings were made using new gold as supplied by the manufacturer. Where re-use of the dental casting gold alloys was being investigated, the buttons from previous castings were first cleaned by heating on a charcoal block with borax powder till they balled up.

(ii) Cylindrical Castings.

Perspex rod, 1" long and $\frac{3}{8}$" diameter was used to form patterns for the casting of cylindrical specimens. Investing was carried out as previously described and castings were made using the gas-air centrifugal casting machine, and the Thermotrol. These castings were subsequently sectioned with a fine saw and pieces from the same casting were studied for effects of heat treatment and for soldering.
(iii) Cast Tensile Test Specimens.

Dumb-bell shaped specimens were prepared for testing tensile strength in a Hounsfield Tensometer*. Patterns for these specimens were prepared using perspex rod with wax ends. The dimensions of these specimens are shown in Figure 1(a).

Casting of the tensile test specimens was effected using the ThermoTroil. After casting, no machining was carried out because of a possible influence on the properties of the cast specimens. Accurate dimensions of the casting were determined using a micrometer, before the tensile test was made.

(iv) Cylindrical Castings for Bend Tests.

Castings were made 1½" long using 18 gauge hypodermic needles as sprue and pattern. These castings were subsequently sectioned and soldered, and later subjected to bending to allow observation of the path of fracture to be made.

(v) Cylindrical Castings for Contact Point Soldering Studies.

Cylindrical castings similar to those described (Type ii) were made and subsequently sectioned, polished, for use in a simulated contact point soldering study.

CAST TENSILE TEST SPECIMEN

Figure 1a
SOLDERING.

Investment soldering was employed. The parts to be joined were first assembled. The joint area was waxed up and the parts which might be either inlay castings or cylindrical castings, were then invested with Investo No. 4 Universal Grey Investment which has little or no expansion on heating. The invested assembly was allowed to set for at least one hour. The wax was then removed with boiling water and vaseline type flux (S.S. White or Jelenko) was applied in small amounts to the joint area while the invested block was still warm.

Actual soldering was carried out using a gas-air blow-torch or an electric furnace.

When using a gas-air blowtorch for soldering, the assembled and invested block was placed on a wire gauze over a low gas flame which was gradually turned up over a period of 45 minutes. A small piece of 18K gold solder coated with flux, either vaseline type or powder type, was placed onto the joint area. A brush flame was used to heat the block and a reducing flame was used to melt the solder. Once the solder flowed, the flame was removed and soldering completed. The soldering block was then bench cooled for 2 - 3 minutes before quenching and pickling in sulphuric acid.

For soldering in an electric furnace, the piece of
fluxed gold solder was placed onto the area of the joint. The block was then placed in an electric furnace and taken to 850°C at the rate of 20°C per minute. The 18K gold solder would melt at 750°C. Bench cooling was carried out before quenching and pickling.

Some soldering was carried out using borax powder as a flux to replace the vaseline based flux, and some specimens were soldered without flux.

Contact Point Soldering.

This was carried out on Types I, II and III dental casting gold alloys. Small sections of cylindrical castings were cut and a flat surface polished dentally. This flat surface was then regarded as the proximal surface of an inlay whose contour was to be built up. The area to be soldered was outlined with pencil lead or colloidal graphite. A small piece of gold solder coated with vaseline type of flux was placed within the outlined area and the casting was held with a pair of soldering tweezers over a bunsen flame till the solder melted. Cooling, quenching and pickling were performed as usual.

HEAT TREATMENT.

A study of the effects of heat treatment was made on individual castings, soldered castings, small sections of the same cylindrical casting.
Softening heat treatment was carried out by heating the casting to 700°C and holding at that temperature for 10 minutes before quenching.

For hardening heat treatment, the casting was first subjected to the softening heat treatment and then hardened by heating to 450°C and then cooling from 450°C to 250°C over a period of 15 - 30 minutes.

TEST METHODS.

Studies have been made on the prepared specimens of microstructure and physical properties.

The physical property probably considered most important is that of strength, since reduced strength would almost certainly contribute most to failure of a soldered joint.

Studies of tensile strength have been made, but great difficulty was associated with standardization of this type of test, because of the nature of the method of forming the soldered joint. An attempt has been made to establish the relationship between hardness and tensile strength of cast gold alloys, and soldered joints.

Hardness tests were carried out using the Miniload Hardness Tester*. A load of 100 gm. with a dwell period of 20

* Ernest Leitz, Wetzlar, Germany.
seconds was employed. Measurement of the indentation with its conversion from the table supplied would give the Vickers Hardness Number (VHN) of the specimen tested. Determinations were made both on castings and solder in the "as supplied", "as cast", "after soldering", "softened" and "hardened" conditions.

All values reported are the means of ten indentations on five different specimens.

Tensile strength tests were carried out using a HounsfieId Tensometer. The tensometer was used to test the tensile strength of dental casting gold alloys in the as cast or heat treated conditions, and soldered joints. Fractured specimens were then mounted and polished for metallographic examination and hardness determinations. Tensile test results are the means obtained for three specimens.

**Specimen Preparation for Metallographic Examination and Hardness Testing.**

Specimen preparation was carried out using the method described by Samuels (1953, 1967) using diminishing grades of abrasives.

(a) The specimen was mounted in a cavity prepared in lucite rod, using self curing acrylic resin.

(b) The specimen was ground, on a flat glass bed, under a constant stream of cold water until a satisfactory area for
observation was exposed. This stage of specimen preparation was carried out using Silicon Carbide papers 220, 400, 600.

(c) The specimen was ground with light hand pressure on an "alumina - wax" lap to produce a flat specimen.

(d) The specimen was ground on a slowly revolving cloth-covered wheel charged with diamond paste. Two grades of paste were used. A paste with 4 - 8 micron particles was followed by a paste with 0 - 1 micron diamond particles. A 50 per cent propylene glycol - water mixture was used as a lubricant while polishing on the metallurgical lathe. The use of diamond pastes ensures the removal of disturbed metal introduced during earlier stages of polishing and produces for examination a surface truly representative of the structure of the material.

All specimens for hardness determinations and microscopic observations were prepared as previously outlined.

Etching.

Although the manipulations involved in etching a metallographic specimen were relatively simple to carry out, a certain amount of judgment was required on the part of the operator to secure a satisfactory etched surface. Freshly prepared aqua regia (3 HCl : 1 HNO₃) was used as an etching reagent in this investigation. It was applied to the prepared
surface of a specimen by swabbing lightly with a tuft of soft cotton thoroughly saturated with the etching reagent. When etching has progressed for a time believed sufficient to produce a satisfactory etched surface, the specimen was removed from the etchant and quickly plunged into a stream of cold running water. This procedure immediately stopped the action of the etching reagent and thoroughly removed from the specimen surface all traces of reagent. The specimen was then rinsed in ethyl alcohol to remove water droplets, and subsequently dried in a stream of air.

The etched specimen was now ready for microscopic examination. If the structure has not been completely and satisfactorily revealed at the magnification of interest, the specimen may be etched for a longer time. A specimen that was over-etched could be corrected only by repolishing on the metallurgical polishing lathes and then re-etching for a shorter time.

Specimens were examined using a Zeiss Neophot II Metallograph*, at magnifications of 50X and 1000X.

* Carl Zeiss, Jena, East Germany.
Bend Tests.

A form of bend test was employed to attempt to make a qualitative assessment of fractures, of soldered joints.

Cylindrical specimens were prepared and soldered together, end to end. The soldered specimens were mounted in a piece of perspex rod 1" diameter and ½" high. The long axis of the soldered specimen was parallel to the flat end of the rod. These specimens were then polished, for metallographic examination, using the method previously described.

Saw cuts, at right angles to the specimen, ending approximately 1 mm. from the specimen, were made through the mounting perspex, from each side. Bending of the specimen, through the soldered joint, was carried out using a wedge, in the saw cuts, to cause deflection. Deflections through an angle of 10° were carried out alternately from each side in an attempt to fracture the specimen (Fig. 1b).

Observations were made on unetched and etched specimens, up to twenty deflections. The soldered joints were studied, at various stages, at magnifications of 50X and 1000X, and photomicrographs were taken.
BEND TEST SPECIMEN

Figure 1b
Statistical Analysis.

Except where otherwise stated, all values presented represent the mean of five specimens.

Standard deviations were calculated using the formula:

\[
SD = \sqrt{\frac{\sum (\bar{x} - x)^2}{N - 1}}
\]

\(\bar{x}\) was the mean value for \(N\) specimens
\(x\) was the value for a single specimen
\(N\) was the number of specimens.

The statistical significance of the difference between two means was determined using the "t" test (Spiegel, 1961).

\[
t = \frac{x_1 - x_2}{\sqrt{\frac{N_1 s_1^2 + N_2 s_2^2}{N_1 + N_2}} \times \frac{N_1 + N_2}{N_1 N_2}}
\]

\(s\) was the standard deviation, and the numbers 1 and 2 represented the two values being compared.

The difference between two means has been considered to be "statistically" significant when the "t" test indicated that the difference occurred at the 98 per cent confidence level or greater.
RESULTS.

BASIC FACTORS ON PARENT METALS AND SOLDERED JOINTS.

Porosity.

Porosity occurred in almost every dental gold casting studied. The amount of porosity depends on many factors, but correct melting of the gold alloy, during the casting procedure, appears to be one of the most important factors involved.

Despite every effort to cast correctly, taking into account such factors as: (i) large sprues,

(ii) sufficient metal,

(iii) use of reducing portion of the gas-air flame,

(iv) proper use of the centrifugal casting machine,

porosity was found to be constantly present. Porosity was also found to be constantly present in castings made using the Thermotrol casting machine, in which melting of the alloy is carried out electrically, under optimal conditions in a carbon crucible producing a reducing environment.

No attempt has been made to analyse the causes of porosity, in this study. Ryge et al (1957) and Leinfelder et al (1963) have studied the causes of porosity in dental castings,
and reported at some length on this aspect of the casting procedure.

The effects of the re-use of casting gold alloys can be seen in figure 2. Figure 2(a) shows a typical casting made using new gold while 2(b) and 2(c) show castings made by re-using gold twice and ten times respectively. Figure 2(d) shows a casting where some new gold has been added to gold which is being re-used.

From the porosity present in figure 2, it can be seen that the casting in figure 2(b) was most porous. The porosity in figure 2(a), (c) and (d) was not significantly different. The reason for the significantly increased porosity in figure 2(b) is not clear as the same care in casting was exercised here as in the other castings. From figure 2 it may be seen that, with proper melting and cleaning of the gold alloy, the re-use of casting gold alloy up to ten times, will give a satisfactory casting even at the microscopic level. The use of some new gold, where re-use of gold alloy is being made, did not significantly improve the quality of the gold casting.

A measure of the effect of casting methods and the re-use of gold on the physical properties of casting gold alloy may be seen in table II. It can be seen that the mean hardness values for castings made, using a gas-air melting and centri-
(a) New Gold.  
(b) Cast Twice.

(c) Cast 10 Times.  
(d) Cast Twice + New Gold.

Precious Metal C Gold x50.
Figure 2.
**TABLE II.**

The Effect of Casting Methods and the Re-use of Casting Gold Alloy on the Hardness of the Casting (Precious Metal C Gold).

<table>
<thead>
<tr>
<th>Casting</th>
<th>Hardness (V.H.N.)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CENTRIFUGAL (gas-air)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Gold</td>
<td>146</td>
<td>5.3</td>
</tr>
<tr>
<td>Cast Twice (without additional new gold)</td>
<td>143</td>
<td>9.6</td>
</tr>
<tr>
<td>Cast Twice (with additional new gold)</td>
<td>145</td>
<td>8.3</td>
</tr>
<tr>
<td>Cast 10 Times (without additional new gold)</td>
<td>142</td>
<td>5.6</td>
</tr>
<tr>
<td>THERMOTROL (electric)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Gold</td>
<td>147</td>
<td>5.5</td>
</tr>
<tr>
<td>HAND SWINGER (gas-air)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Gold</td>
<td>143</td>
<td>5.5</td>
</tr>
</tbody>
</table>
Fugal casting machine, Thermotrol casting machine, or hand swinger with gas-air melting, were not significantly different. Similarly, the re-use of gold alloys has no significant effect on the hardness values of gold castings. The significance of the relationship between the Vickers Hardness (VHN) and Ultimate Tensile Strength of the casting gold alloy, (see page 91.), leads to the conclusion that these techniques of casting, and the re-use of gold alloys have no significant effect on the tensile strength of gold castings.

Porosity in casting gold alloys and gold solders occurs, after melting these alloys. Figure 3(a) shows a photomicrograph of Precious Metals C gold as supplied by the manufacturer and figure 3(b) shows a typical casting made from this alloy. Figure 3(c) shows a piece of 18K gold solder as supplied by the manufacturer and figure 3(d) is a photomicrograph of gold solder after heating on a charcoal block, till it balls up, and then cooling.

There is a significant increase in porosity in both the casting gold alloy and the gold solder after heating.

Hardness determinations, shown in Table III, indicated that mechanical properties are decreased after heating these alloys above their melting points. It was observed that the original hardness of the casting gold alloy could not be re-established despite subjecting the casting to hardening heat
(a) Precious Metal C Gold as supplied.

(b) After Casting.

(c) 18K Gold Solder as supplied.

(d) After Melting.

X50.

Figure 3.
**TABLE III.**

The Effect of Heating and Casting on Dental Casting Gold Alloy and Gold Solder.

<table>
<thead>
<tr>
<th>Gold Alloy</th>
<th>Hardness (V.H.N.)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>New C Gold (Precious Metal): As Supplied</td>
<td>257</td>
<td>17.6</td>
</tr>
<tr>
<td>After Melting and Casting (As Cast)</td>
<td>145</td>
<td>8.3</td>
</tr>
<tr>
<td>After Melting and Casting (Hardening Heat Treatment)</td>
<td>170</td>
<td>9.7</td>
</tr>
<tr>
<td>18K Gold Solder:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>As supplied</td>
<td>250</td>
<td>15.6</td>
</tr>
<tr>
<td>Heated till balls up</td>
<td>164</td>
<td>7.1</td>
</tr>
</tbody>
</table>
treatment. In view of the fact that both the casting gold and the solder are supplied in a wrought form, which has been subjected to considerable work hardening, it is not surprising that the original physical properties cannot be regained.

The relationship between the hardness (V.H.N.) and tensile strength will be discussed in a subsequent section.

Figure 4 shows photomicrographs of two soldered joints. Both soldered joints were macroscopically satisfactory. After sectioning it was found that the porosity in the solder area was approximately the same as the porosity in the castings.

The porosity in both castings and solder in figure 4(a) is less than the porosity in castings and solder in figure 4(b). The presence of porosity in the original casting seems to bear some relationship to the porosity in the solder. It is particularly noticeable in figure 4(a) that the dark voids in the solder are concentrated along the margins bordering the original castings. The void in region A in figure 4(a) crosses the soldered joint and probably has originated in the casting and, due to gassing, has involved the solder. In figure 4 there can be seen some spherical voids in the solder which may be flux voids. The influence of flux will be discussed on page 77.

Grain Size.

The size of the grains has an important bearing on the
(b) Soldered Castings (unetched)
X50.
Figure 4.
physical properties of cast dental gold alloys. The smaller
the grain size, and consequently the more grains per unit area,
the stronger a particular alloy should be. The operator has
some control over grain size, in an attempt to produce a dental
structure with superior properties. The rate of solidification
of the alloy is a variable influencing grain size.

Figure 5 shows the microstructure of two dental
castings following etching. Figure 5(a) is a photomicrograph
of a casting made using the Thermotrol casting machine with
electric melting of the metal, while figure 5(b) is a casting
made using a gas-air blowtorch and a centrifugal casting machine.
Both castings are Precious Metals C type gold.

Comparing the grain structures of the castings, it can
be seen that the grains in the Thermotrol casting are significantly
larger than those of the casting made using a gas-air blowtorch.
This finding has been a constant observation in this investiga-
tion and is due to the fact that in castings made using the
Thermotrol, cooling and solidification of the metal is slower
because of the continued proximity of the heated crucible to the
casting. Despite the larger grain size in castings made using
the Thermotrol, the physical properties of these castings are not
necessarily inferior to gas-air castings and in fact may be
superior because of a greater control of other factors such as
porosity.
Thermotrol
one piece
casting.

Gas-air
one piece
casting.

Precious Metal C Gold X50.
Figure 5.
Figure 6 demonstrates the structures of typical castings made using the dental gold alloys used in this investigation. All these castings were made using the gas-air centrifugal casting machine and are typical of the type.

The grain size in the Jelenko Fimilay (Type C gold alloy) castings was very large compared with those of Precious Metal C gold, their size being approximately the same as castings made using Precious Metal C gold and the Thermotrol.

Jelenko Moduley (Type B) and Precious Metal B gold had similar microstructures.

Precious Metal A gold had very large grains.
(a) Precious Metal C Gold.  (b) Jelenko Firmilay.

(c) Precious Metal B Gold.

(d) Jelenko Modulay.  (e) Precious Metal A Gold.

X50.

Figure 6.
SOLDERING VARIABLES.

Electric Soldering Versus Gas-Air Soldering.

Figure 7 shows photomicrographs of soldered joints. The castings consisted of Precious Metal C gold alloy, cast using gas-air and a centrifugal casting machine. Figure 7(a) shows a joint which has been soldered in an electric furnace at 850°C, and figure 7(b) shows a joint where the soldering operation has been carried out using a gas-air blowtorch.

Following soldering electrically the joint was found to be satisfactory macroscopically and microscopically. Alloying has occurred between the gold solder and the parent casting alloys. Grain boundaries may be seen to be continuous across the soldered joint and the grain sizes within the solder and the parent metals are the same. In figure 7(b) there appears to be lack of alloying. Dark vacancies can be seen between the solder and the castings in several areas, the grain sizes in the solder and the parent metals are significantly different, the grains in the solder being smaller than those in the castings, and there is lack of continuity of grain boundaries across the solder - gold alloy interface.

Flux.

The use of flux is essential in the soldering operation.
(a) Electric Soldering.

(b) Gas-air Soldering.
Precious Metal C Gold.
X50

Figure 7.
Both borax powder and vaseline based fluxes were found to be satisfactory for soldering with a gas-air blowpipe. Vaseline based fluxes were found to be more satisfactory for soldering in an electric furnace. With the use of flux, flux voids in the form of large globules were often found in soldered joints, at the microscopic level. These globular voids were observed as an almost constant factor where flux was used.

Figure 8 shows the presence of globular flux voids in two soldered joints.

The results of soldering without flux are seen in figure 9. Soldering without flux required prolonged heating at a higher temperature. The solder did not appear to flow during the soldering operation, but on cooling, the joint was adjudged to be satisfactory macroscopically. Figure 9(a) is a photomicrograph of a joint where alloying appears to be complete, and is somewhat similar to figure 7(a). The shape of the joint is probably due to the fact that heating to an extremely high temperature for a prolonged time has actually melted the casting allowing alloying to take place and producing a wider soldered joint with concave faces on the parent metals. Originally the surfaces of these castings were flat. Figure 9(b) shows a less successful joint, soldered without flux, in which some melting of the original castings has taken place without union occurring.
Flux Voids X50.

Figure 8.
Note: Diamond hardness indentations.

Soldering without Flux X50.

Figure 9.
Air Entrapment.

Figure 10 shows a large void occurring in a soldered joint. This void was not obvious before sectioning and this joint was considered to be satisfactory clinically. Such voids have been observed on a number of occasions and almost certainly are due to trapping air while soldering. Air entrapment may occur more readily if the solder melts from both sides of a joint at the same time due to the use of too large a flame with the gas-air blowtorch.

Grain Growth.

Grain growth occurs in the parent alloys whenever soldering is carried out. Figures 11 and 12 show evidence of grain growth having occurred during soldering.

In Figure 11(a) a one piece casting of two adjoining gold inlays is shown. This has been cast using gas-air, and shows a typical grain structure for this type of casting using Precious Metal C gold. Figure 11(b) shows the typical grain size after soldering using a gas-air blow pipe (open flame).

Figure 12 compares a one piece casting, Precious Metal C gold, made with the Thermod, and two castings made using the Thermod and subsequently soldered using a gas-air blow pipe. The variation in grain size between the parent alloys and the solder may be clearly seen in these photomicrographs.
Air entrapment -

C Gold Thermotrol Cast X50.

Figure 10.
(a) Gas-air Casting Unsoldered.

(b) Gas-air Castings Soldered.

X50.

Figure 11.
(a) Thermotrol Casting Unsoldered.

(b) Thermotrol Castings Soldered.

X50.

Figure 12.