Amalgam I

Aim

- To introduce dental materials aspects related to amalgam fillings as used in contemporary dental practice

Objectives

- Definition.
- Compositions.
- Types.
- Applications.

Defintion

- amalgam n: 1: an alloy of mercury 2: dental amalgam is an alloy of mercury, silver, copper, and tin, which may also contain palladium, zinc, and other elements to improve handling characteristics and clinical performance.

GPT 2005

Definition

- Dental amalgam is produced by mixing liquid mercury with solid particles of an alloy of silver, tin, copper, and sometimes zinc, palladium, indium and selenium

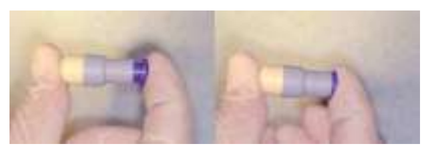
Amalgam in dental practices

- Uses:
  *Direct, permanent, posterior restorations
  *Large foundation restorations
  *Cores for crown or fixed partial denture restorations (Nayyar core).

A journey of an amalgam capsule

Amalgam capsule

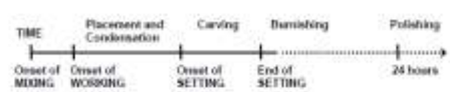
When activated



Condensation

Burnishing

Carving



Advantages of amalgam

- Easy to insert
- Not overly technique sensitive
- Maintain anatomical form
- Have adequate resistance to fracture
- Prevent marginal leakage after a period of time in the mouth
- Can be used in stress bearing areas
- Have a relatively long service life (>8 years)

Disadvantages

- Not tooth colored
- Relatively brittle
- Subject to corrosion and galvanic action.
- May demonstrate a degree of marginal breakdown
- Do not help retain weakened tooth structure,
- Alleged mercury toxicity, both on personal and environmental level

Composition

- Essential elements of amalgam alloy:

- Silver (Ag)

-Tin (Sn)

- Other elements:

-Copper

-Zinc

-Gold

-Palladium

Role of elements

Ag: Main reactant

Sn: creates Fluidity and solubility

Cu: Reacts with Sn

Zn: To facilitate production of alloy

Hg: Reactant with Ag and Sn

- Zinc

= Deoxidizer: a scavenger (O_2) during melting → ↓formation of oxides

- Can cause an abnormal expansion if the amalgam is condensed in the presence of moisture

Basic reaction

Amalgam alloy + Mercury (Hg) → Amalgam

Phases in Amalgam Alloys and Set Dental Amalgams	Formula
γ	Ag_3Sn
$γ_1$	Ag_2Hg_3
$γ_2$	$Sn_{7-8}Hg$
β	Ag_4Sn (silver-rich)
ε	Cu_3Sn
η	Cu_6Sn_5
Silver-copper eutectic	Ag-Cu

- ANSI/ADA Spec. #1 (ISO 1559) requires that amalgam alloys be predominantly silver (Ag) and tin (Sn).
  - containing Zn > 0.01% → "Zinc Containing"
  - containing Zn ≤ 0.01% → "nonzinc"

Alloy types based of production technique.

- Lathe cut

Metal ingredients →heated →poured into a mold → ingot (Ag_3Sn (γ) + some β,ε, η)
Ingot → homogenizing anneal
An annealed ingot of alloy is place in a machine and is fed into a cutting tool.
60-120 µm in length, 10-70 µm in width
Some aging of the alloy is desirable

Lathe cut

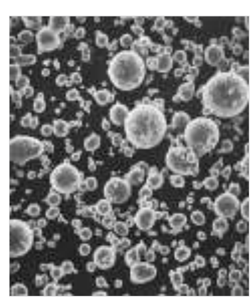
Homogenizing Anneal

- The ingot is placed in an oven and heated at a an elevated temperature (at 400°C) for sufficient time (6-8 hours) to allow diffusion of the atoms to occur and the phases to reach equilibrium.

- Spherical

Made by melting the desired elements together
The liquid metal is atomized into fine spherical droplets of metal by being sprayed under high pressure of an inert gas.
→ "Spherical powders" 2- 43 µm
Also have heat treatment and are usually washed with acid.

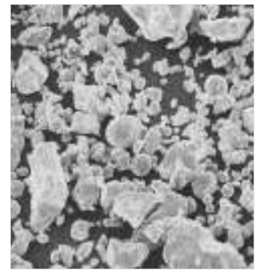
Spherical



- Admix

A mix of both lathe cut and spherical

Admix



- Lathe-cut or admixed powders resist condensation better than spherical powders.
- Spherical alloys require less mercury than typical lathe-cut alloys because of the smaller surface area per volume.
  - Amalgams with a low mercury content generally have better properties.

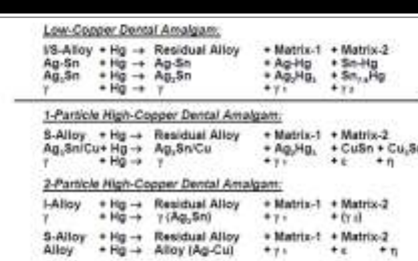
- **Low-copper (Conventional) amalgam alloy**
  (at least 65 wt% Ag, 29 wt% Sn, < 6 wt% Cu)
  - lathe-cut (irregular) powder or spherical particles or mixed
  - Ag-Sn
- **High-copper amalgam alloy**
  (6-60 wt% Cu)
  - (1) Admixed (Ag-Sn + Ag-Cu)
    - A mixture of irregular and spherical particles of different or same composition
  - (2) Unicomposition or Single composition (Ag-Sn-Cu)
    - All spherical particles

Trituration process

Amalgam alloy is mixed with mercury.

“Amalgamation Process”
- Mercury dissolves the surface of alloy particles → a composite plastic mass (some new phases form).
- Setting and hardening occur as the liquid mercury is consumed in the formation of new solid phases.

Setting reactions



Low-Copper Dental Amalgam:

I/S-Alloy	+ Hg →	Residual Alloy	+ Matrix-1	+ Matrix-2	
Ag-Sn	+ Hg →	Ag-Sn	+ Ag-Hg	+ Sn-Hg	
Ag_3Sn	+ Hg →	Ag_3Sn	+ Ag_2Hg_3	+ $Sn_{7-8}Hg$	
γ	+ Hg →	γ	+ γ_1	+ γ_2	

1-Particle High-Copper Dental Amalgam:

S-Alloy	+ Hg →	Residual Alloy	+ Matrix-1	+ Matrix-2	
Ag_3Sn/Cu	+ Hg →	Ag_3Sn/Cu	+ Ag_2Hg_3	+ CuSn	+ Cu_3Sn
γ	+ Hg →	γ	+ γ_1	+ ε	+ η

2-Particle High-Copper Dental Amalgam:

I-Alloy	+ Hg →	Residual Alloy	+ Matrix-1	+ Matrix-2	
γ	+ Hg →	γ (Ag_3Sn)	+ γ_1	+ (γ_2)	
S-Alloy	+ Hg →	Residual Alloy	+ Matrix-1	+ Matrix-2	
Alloy	+ Hg →	Alloy (Ag-Cu)	+ γ_1	+ ε	+ η

Low Cu alloy mixing

- When the solubility is exceeded, crystals of two binary metallic compounds precipitate into the mercury.
  - Ag_2Hg_3 compound (γ_1) precipitates first.
  - $Sn_{7\text{-}8}Hg$ compound (γ_2) precipitates later.
  - As the remaining mercury dissolves the alloy particles, γ1 and γ2 crystals grow.

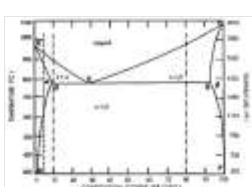
- As the mercury disappears, the amalgam hardens. Particles become covered with newly formed crystals, mostly γ_1
- Unconsumed particles (smaller after being partly dissolved) are surrounded and bound together by solid γ1 and γ2 phases

- A typical low-copper amalgam is a composite in which the unconsumed particles are embedded in γ_1 and γ_2 phases
- Physical properties
  1. γ-phase → strongest, γ_2 phase → weakest
  2. Hardness: $\gamma > \gamma_1 >>> \gamma_2$
  3. γ_2 → poor corrosion resistance

High Cu Admix alloys

- Ag dissolves into the Hg from the Ag-Cu alloy particles.
- Both Ag and Sn dissolve into Hg from the Ag-Sn alloy particles. *(same as in low-Cu alloy)*
- Sn in solution diffuses to the surface of Ag-Cu alloy particles and reacts with the Cu to form the η phase (Cu_6Sn_5) *(therefore, the $Sn_{7\text{-}8}Hg$ or γ2 is eliminated)*

- Silver-Copper eutectic alloy
  - 71.9 wt% Ag, 28.1 wt% Cu



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High Cu uni compositional alloys

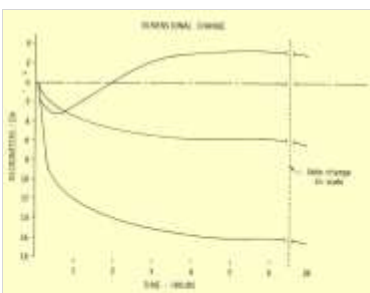
- Each particle has the same chemical composition.
- Major components: Ag-Cu-Sn
- Phases found in each single-composition alloy particle are β (Ag-Sn), γ (Ag_3Sn), and ε (Cu_3Sn).
- η crystals are found as meshes of rod crystals at the surfaces of alloy particles (P), as well as dispersed in the matrix
- Little or none of γ_2 phase can form.

Properties of dental amalgam

- Dimensional changes:

ADA spec. #1: amalgam neither contract nor expand more than 20 µm/cm between 5 min and 24 hours after beginning of trituration.

Dimensional change



- Contraction results as the particles dissolve and the γ_1 grows.
- If there is sufficient liquid mercury present to provide a plastic matrix, expansion will occur when γ_1 crystals impinge against one another.
- Zinc-containing amalgam contaminated by moisture during trituration or condensation → *delayed* or *secondary expansion*.
  - Zn ≡ water → H_2 collected within the restoration → creep

- Lower Hg:alloy ratios and higher condensation pressures → less Hg in the mix → contraction
- Longer trituration times, use of smaller particle size alloys → accelerate setting → contraction.
- Modern amalgams → contraction
  - ↓Hg:alloy ratio
  - ↑Speed of trituration

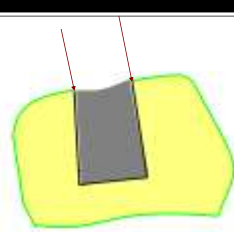
- Contraction of amalgam → marginal leakage
- If amalgam expanded during hardening, leakage around the margins of restorations would be eliminated.
- The detrimental effect of shrinkage occurs only when the amalgam mass shrinks > 50 µm. (ADA allows 20 µm/cm shrinkage)

Corrosion

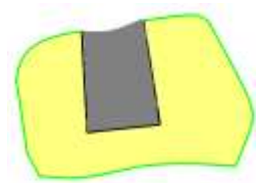
- Order of corrosion resistance (in pure phases)
  - Ag_2Hg_3 (γ_1) > Ag_3Sn (γ) > Ag_3Cu_2 > Cu_3Sn (ε) > Cu_6Sn_5 (η) > $Sn_{7\text{-}8}Hg$ (γ_2)
- In the low-Cu amalgam, the most corrodible phase is the $Sn_{7\text{-}8}Hg$ (γ_2) (11-13% of amalgam mass).
  - Corrosion → liberated Hg + Tin oxide or Tin Chloride
  - → porosity and lower strength
- Gold v.s. amalgam restorations
  - Galvanic corrosion
  - Free mercury can weaken the gold restoration.

- High Hg:alloy ratio → formation of γ_2 phase → promoting corrosion
- Gold v.s. amalgam restorations
  - Galvanic corrosion
  - Free mercury can weaken the gold restoration

- The space between the alloy and the tooth permits the microleakage of electrolyte, and a classic concentration cell process results.



- The build-up of corrosion products gradually seals this space, making dental amalgam a self-sealing restoration.
- Most common corrosion products = oxides and chlorides of Sn



Mechanical properties

- Compressive strength: the most favorable feature of amalgam
- Amalgam is a viscoelastic material.
  What does this mean???
- High Cu, unicompositional has the highest initial and delayed compressive strength
  What are the advantages??

Tensile strength

- Only a fraction of compresive strength.
  What are the implications in cavity design.
- Final t ensile strength are the same for different types.
- High cu alloys attain much higher intial tensile strength.
  What advantages?

Transverse strength

- What are the implications for the base materials under the amalgam?

- Mercury content
  - The strength of an amalgam is a function of the volume fractions of unconsumed alloy particles and mercury-containing phases.
  - Inadequate Hg → a dry, granular mix → a rough, pitted surface → corrosion
  - Excess Hg left → reduction in strength

- Condensation
  - Lathe-cut alloys
    - Greater condensation pressure → higher compressive strength
  - Spherical amalgams
    - Lighter condensation pressure → adequate strength
    (Heavy pressure → condenser may punch through the amalgam.)

- Porosity
  - Related to the plasticity of the mix
  - Increasing condensation pressure → improved adaptation and decreases the number of voids

- Amalgam hardening rate
  - When will amalgam gain sufficient strength for its function? (chewing, core preparation,..)
  - ADA spec. → min compressive strength 80 MPa at 1 hour
    - High-Cu single-composition amalgams may be strong enough shortly after placement to permit amalgam build-ups to be prepared for crowns.
    - Patients should be cautioned not to subject the restoration to high biting stresses for at least 8 hours after placement.

Creep

- Creep rate has been found to correlate with marginal breakdown of conventional low-cupper amalgams.
  - Higher creep → greater marginal deterioration
  - ADA spec. #1: creep rate < 3%

- Microstructure v.s. Creep
  - Low-Cu
    - Larger γ_1 volume fraction → ↑creep rate
    - Larger γ_1 grain sizes → ↓creep rate
    - Presence of γ_2 → ↑creep rate
  - Single-composition high-Cu amalgams
    - η rods limit the deformation of γ_1 phase

Manipulation

- Alloy selection!
- Mixing (trituration), high speed
- Effect on creep:
  - -/+ 2 to 3 seconds → undermixed (dry and crumbly) or overmixed (soupy and tends to stick to the capsule)
  - Effect on working time and dimensional change
    - Overtrituration → decreases working time, slightly higher contraction
  - Effect on strength
    - Overtrituration → increases strengths in lathe-cut alloys
    - Both over- and undertrituration → decrease strengths in spherical alloys and admixed high-Cu alloy
  - Effect of creep
    - Overtrituration → increases creep
    - Undertrituration → decreases creep

Condensation

- The more Hg left in the mass after condensation, the weaker the alloy. → Great condensing force should be used.
- Hand v.s. Mechanical condensation
  - Spherical amalgam → large tip condenser

Finishing amalgam restorations

- Decreases tarnish and corrosion
- Low-Cu amalgam restoration should be left undisturbed for at least 24 hours.
- High-Cu unicompositional amalgams with high early strengths can be finished at the first appointment.

Mercury hazards and waste management

Is amalgam toxic???!!

The amalgam controversy
An evidence-based analysis
JOHN E. DODES JADA 2001

Mercury form

- Methyl and ethyl mercury
- Vapour
- Inorganic compounds

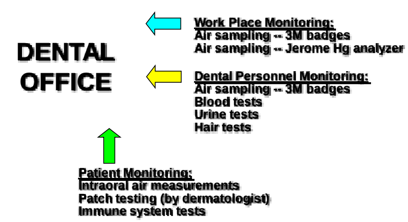
Concentration of mercury

- Threshold value of Mercury vapour: 50 μg/m^3.
- More mercury vapor during removal of amalgam

- Historical Problems:
  Tanners
  Thermometer technicians
  HgS mine workers

  Minamata Bay, Kyushu, Japan (fish problem)
  Iraq (grain problem)
  Alamogordo, NM (grain problem)
- Recent Incidents:
  Sweden (environmental load problem)
  Michigan (distillation problem by lab tech)

Detection of Hg



- Chemical and Electrochemical Corrosion → NO Hg RELEASED

a. Low-copper dental amalgam:			
[Sn-Hg]	→ [Sn] + saliva	→ [Sn-O-Cl]	(soluble)
	→ [Sn] + saliva	→ [Sn-O]	(insoluble)
	→ [Hg] + [Sg-Sn]	→ [Sg-Hg] + [Sn+Hg]	(more rx)
b. High-copper dental amalgam:			
[Cu-Sn]	→ [Sn] + saliva	→ [Sn-O-Cl]	(soluble)
	→ [Sn] + saliva	→ [Sn-O]	(insoluble)
	→ [Cu] + saliva	→ [Cu-Cl]	(soluble)

JADA 2003

- Amalgam contains mercury.
- Some Scandinavian countries has banned the use of amalgam.
- ADA and BDA are against such ban.

GENERAL MERCURY HYGIENE RECOMMENDATIONS

- Training for the staff involved.
- Remove professional clothing before leaving the surgery

OFFICE settings

- Well ventilated.
- Use proper work area design to facilitate spill containment and cleanup. Floor coverings should be non absorbent, seamless and easy to clean.
- Periodically check the dental operatory atmosphere for mercury vapour. This may be done using dosimeter badges or through the use of mercury vapour analyzers for rapid assessment after any mercury spill or cleanup procedure.

HYGIENE RECOMMENDATIONS DURING PREPARATION AND PLACEMENT OF AMALGAM

- Use only pre-capsulated amalgam alloys.
- Use an amalgamator with a completely enclosed arm.
- If possible, recap single-use capsules after use, store them in a closed container and recycle them.
- Use care when handling amalgam. Avoid skin contact with mercury or freshly mixed amalgam.
- Use high-volume evacuation systems (fitted with traps or filters) when finishing or removing amalgam.

Mercury spills

- Never use household cleaning products, in particular those containing Ammonia or Chlorine.
- Never use vacuum cleaners.
- Never allow mercury to go down the drain.
- Never use a paint brush to remove mercury

Amalgam waste management

- http://www.ada.org/prof/resources/topics/topics_amalgamwaste.pdf

Information included are required for the purpose of examination.

Very good luck with your final exams

- "A **smooth sea** never made a skilled mariner"