

DENTAL AMALGAM

Historical Composition

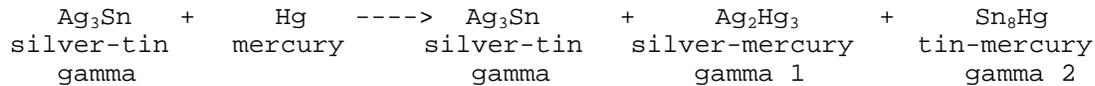
G.V. Black believed that amalgam should consist of:
67% silver, 27% tin, 5% copper, and 1% zinc

Low-Copper (Traditional, Conventional) Amalgam

Composition:

Silver	60%
Tin	29%
Copper	<6%
Zinc	<2%

General Setting Reaction:



When low-copper amalgam is triturated, mercury diffuses into the silver-tin particles and silver and tin dissolve, to a very limited extent, into the mercury. As this occurs, the particles become smaller. Because the solubility of both silver and tin in mercury is limited (0.035 and 0.6 weight percent respectively) and because silver is much less soluble in mercury than is tin, silver precipitates out first as silver-mercury (gamma 1) followed by tin in the form of tin-mercury (gamma 2).

The set amalgam consists of core gamma particles surrounded by a matrix of gamma 1 and gamma 2.

High-Copper (New-Generation, Gamma-2 Free) Amalgam

Composition:

Silver	40% to 70%
Tin	12% to 30%
Copper	12% to 30%
Indium	0% to 4%
Zinc	0% to 1%
Palladium	0.5%

High-copper amalgam was developed in 1962 by the addition of silver-copper eutectic particles to traditional silver-tin lathe-cut particles in an attempt to dispersion strengthen or dispersion harden the alloy.¹ Although clinical tests showed that these new alloys had better physical properties, the improvement was not due to dispersion hardening (because the silver-copper eutectic particles were too large and too far apart to impede dislocation movement) but rather were the result of formation of Cu_6Sn_5 , the eta phase. The fact that tin had a greater affinity for copper than for mercury meant that the

gamma-2 phase was reduced or eliminated. This resulted in the dramatic improvement in physical properties.

It is important to note that high-copper alloys must contain at least 12% copper to eliminate the gamma-2 phase. Compared to their low-copper amalgam counterparts, high-copper alloys exhibit the following physical properties: greater strength, less tarnish and corrosion, and less creep. Overall, they are also less sensitive to handling variables and produce better long-term clinical results.

Purposes of Constituents in Amalgam

Silver -- increases strength and expansion

Tin -- decrease strength and expansion and lengthens the setting time.

Copper -- increases strength, reduces tarnish and corrosion, and reduces creep and, therefore, marginal deterioration. Copper accomplishes these effects by tying up tin, preventing the formation of gamma 2, the weakest, most tarnish- and corrosion-prone phase, and the phase with the highest creep values. In addition, it reduces creep by tying up tin and forming copper-tin (Cu_6Sn_5), the eta phase, whose crystals interlock to prevent slippage and dislocations at the grain boundaries of gamma-1 particles which is a major cause of creep in amalgam. Is added at the expense of the silver. Copper is insoluble in mercury.

Zinc -- is added for the benefit of the manufacturer because it prevents oxidation of the other metals in the alloy during the manufacturing process; in so doing, it keeps the alloy from turning dark. Zinc accomplishes this by combining readily with oxygen to form zinc oxide. An alloy with <0.01% zinc is "zinc-free" while an alloy with >0.01% zinc is "zinc-containing". If a low-copper, zinc-containing alloy is moisture contaminated, it will result in surface blistering, internal corrosion, and a delayed expansion of up to 4% by volume beginning 3 to 5 days after the contamination and continuing for up to six months. This can lead to a reduction in strength of up to 24%.² Although, moisture contamination of zinc-containing high-copper amalgams has not been shown to cause delayed expansion,^{3,4} moisture contamination of all types of amalgam should be avoided because it can cause a reduction in strength. Research has found that high-copper amalgam alloys that contain zinc in a 1% concentration exhibit lower rates of margin fracture than do zinc-free alloys.⁵ This is believed to be due to zinc's behavior as a sacrificial anode which delays corrosion of tin in the Cu_6Sn_5 phase.

Other constituents which may also be present are:

Indium: one study found that an indium-containing admixed

high-copper amalgam exhibited a reduction in creep and an increase in strength.⁶ A clinical study found that 5% and 10% indium-containing alloys exhibited less margin breakdown but a darker appearance and a rougher surface than Dispersalloy.⁷ A five-year clinical study found that there was no significant difference in surface luster or texture between indium-containing alloys (5% and 10%) and Dispersalloy. Marginal breakdown was significantly less for the indium-containing alloys, but the difference was not felt to be clinically significant.⁸ Indium added to an alloy in concentrations of 8% (or more) by mass also was found to significantly reduce the amount of mercury vapor emitted from the restoration, partially because indium decreases the surface tension of liquid metals and therefore reduces the amount of mercury necessary for trituration.⁹ Youdelis also found that less mercury is required for mixing amalgam when it contains indium in concentrations up to 10%.^{10,11} A second reason for lower mercury emission is that amalgam prepared with indium rapidly forms indium oxide and tin oxide films which reduce mercury release.¹² The indium must be in an admixed form, however, to have these beneficial effects. If the indium is added to the molten metal and atomized to produce spherical particles, these effects are not seen. An example of this latter type of indium-containing amalgam was Shofu's Indiloy which contained 4% indium. Biological tests of indium-containing amalgam show that it is no more cytotoxic or hemolytic than standard ADA Certified amalgam.^{13,14} One currently marketed indium-containing amalgam is Indisperse (Indisperse Distributing Company), which contains 5% admixed indium.

Palladium: (in a 0.5% concentration in Ivoclar's Valiant and Valiant PhD to reduce tarnish and corrosion); palladium-containing alloys in vitro have been found to exhibit reduced corrosion rates and in vivo have a slightly greater luster than non-palladium alloys; they do not, however, have significantly lower rates of marginal deterioration.¹⁵ In vivo, palladium has been found in the gamma-1 and eta phases in high-copper amalgams.

Types of High-Copper Amalgams

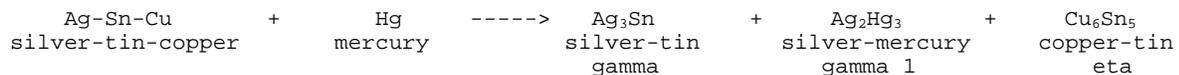
- Single-composition lathe-cut (e.g., Epoque, Jentalloy III, ANA 2000)
- Single-composition-spherical (e.g., Valiant, Tytin, Megalloy, Logic+, Sybraloy)
- Admixture of lathe-cut with spherical silver-copper eutectic particles (e.g., Dispersalloy, Original D, Indisperse, Contour)
- Admixture of lathe-cut with single-composition spherical (e.g., Valiant PhD)

Single-Composition-Spherical (SCS) Amalgams

As a general rule the SCSs are harder, stronger in compression, and have lower creep and corrosion currents, while the admixed lathe-cut with single-composition sphericals have higher creep and corrosion currents. SCS alloys leak more than admixed and lathe-cut ones.¹⁶ This may be due to the less intimate adaptation the SCS amalgams exhibit to the walls of the preparation.¹⁷ With SCS amalgams, mixes of proper plasticity (i.e., wetter mixes) and good condensation techniques can reduce the size of the gap between the amalgam and tooth structure.¹⁸

Generally the SCS alloys require a lower mercury-to-alloy ratio than other types of high-copper amalgams. Some are as low as 41%.

General Setting Reaction:



Note that NO gamma 2 is formed.

When SCS high-copper amalgam is triturated, mercury diffuses into the silver-tin-copper particles and silver and tin dissolve, to a very limited extent, into the mercury. Silver is much less soluble in mercury than is tin, so silver precipitates out first as silver-mercury (gamma 1). Copper in the particles combines with tin to form Cu₆Sn₅ crystals which form on the surface of the particles and in the gamma-1 matrix.

The set amalgam consists of core gamma particles in the matrix of gamma 1 and Cu₆Sn₅.

Representative SCS Alloys:

- Tytin (SDS/Kerr)
 - developed by Kamal Asgar
 - first introduced in 1975
 - is a ternary alloy containing silver, tin, and copper
 - contains Ag 59%, Sn 28%, Cu 13%
 - mercury content is 42.5%
 - gamma particles are spheres formed by aerosol spray into an argon atmosphere
 - no gamma-2 phase is formed
 - come supplied as 400 mg (blue caps), 600 mg (grey caps), and 800 mg (white caps)

- Valiant (Ivoclar Vivadent)
 - is a quaternary alloy containing silver, tin, copper, and palladium

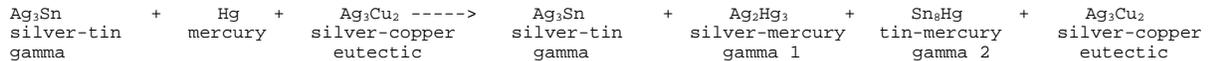
- contains Ag 49.5%, Sn 30%, Cu 20%, Pd 0.5%
- mercury content is 42.7% Hg
- palladium is added to increase corrosion resistance of the silver phase

Lojic+ (Southern Dental Industries)

- surface texture of the spherical particles as well as a wide range of spherical particle size (2 to 56 μm) gives product resistance to condensation
- is a quaternary alloy containing silver, tin, copper, platinum
- contains Ag 60.1%, Sn 28.05%, Cu 11.8%, Pt 0.05%
- mercury content is 42.2% Hg
- platinum is added to increase product's tensile and compressive strength by five percent

Admixture of lathe-cut with spherical silver-copper eutectic particles (ALE) Amalgams

General Setting Reaction:



The second portion of the reaction involves the gamma 2 and the silver-copper eutectic.



As admixed high copper amalgam is triturated, mercury diffuses into the silver-tin particles and silver and tin dissolve, to a very limited extent, into the mercury. Silver from the silver-copper eutectic particles also enters the mercury. Copper combines with tin forming a ring of Cu_6Sn_5 around the eutectic particles while the silver precipitates out as gamma 1.

The final set amalgam consists of core gamma and silver-copper eutectic particles in a matrix of gamma 1. The eutectic particles are surrounded by the eta phase.

Representative ALE Alloys:

Dispersion alloy (Dentsply/Caulk)

- first introduced in Canada by Youdelis in 1968 as the first high-copper alloy; was the first "dispersion hardened" amalgam; development was based upon dispersion hardening (strengthening)

of metals which occurs when a large volume fraction of ultra fine particles (usually <1 micron) is dispersed throughout the metal; it was believed that the silver-copper particles would act to impede dislocation movement and strengthen the amalgam; the properties did improve but the improvements were a result of the higher concentrations of copper tying up tin and reducing gamma 2 formation

- is 2/3 conventional lathe-cut alloy with 3% Cu, and 1/3 eutectic consisting of 71.9 weight% Ag, and 28.1 weight% Cu
- contains 69.3% Ag, 17.9% Sn, 11.8% Cu, 1% Zn; 50% Hg is triturated with this alloy

Original D (Wykle Research, Inc.)

- manufactured since 1988

- contains 69.5% Ag, 17.5% Sn, 12% Cu, 1% Zn, and 49.9% Hg

Admixture, Lathe-cut plus Single Composition Spherical (ALSCS)

As a general rule the ALSCSs have higher creep and corrosion currents than the other three types of high-copper amalgams.

Representative ALSCS Alloy:

Valiant Ph.D. (Ivoclar Vivadent)

- is 40% lathe-cut alloy with 60% spherical

- contains 19% Cu and also 0.5% Pd to increase corrosion resistance

- contains 47.6% Hg

Mercury Content

Residual mercury refers to the amount of mercury present in the fully reacted alloy. It does not refer to free elemental mercury, because none exists; it is all consumed within two hours of trituration.¹⁹ Residual mercury levels are highest on the surface and at the margins of a restoration. Certain manipulative factors such as poor condensation technique and delaying between trituration and condensation can increase residual mercury levels.²⁰ Using alloys which require high mercury-to-alloy ratios can also result in high residual mercury levels.

Amalgam restorations contain approximately 41% to 51% mercury by weight.²¹ The ideal range of residual mercury is from 44 to 48%;²² mercury concentrations should not exceed 55% as this leads to decrease in strength.²³ It may also result in decreased

tarnish and corrosion resistance and increased creep because the mercury converts gamma to gamma 1 and gamma 2.

Single-composition spherical amalgam alloys require a lower mercury-to-alloy ratio because their spherical particles have a smaller surface area; less mercury is required to wet them compared to the particles found in single-composition lathe-cut or admixed alloys. Admixed alloys, on the other hand, contain lathe-cut particles with cracks and flaws, so they require a higher mercury-to-alloy ratio and longer trituration times to wet the particles adequately with mercury.

It is desirable from a physical property standpoint to make the amalgam with the smallest amount of mercury necessary to produce a workable mix; anything in excess of this amount will be used to produce more of the gamma-1 and gamma-2 phases.

As amalgam corrodes, mercury is released and reacts with the unreacted alloy (gamma).²⁴ Because the phases in amalgam are not in equilibrium, mercury is rearranged within it as some of the phases form and some decompose.²⁴

Manufacturing of Amalgam Alloy

Lathe-cut alloys are produced by cooling molten 72% silver and 28% tin and forming an ingot. The alloy is heated for 8 hours at 400°C to homogenize its composition. The homogenization heat treatment is required to modify the alloy's composition which affects its setting time. After the ingot is lathe-cut to produce the particles, they are further ball-milled to reduce their size.

Since these two machining operations impart energy to the particles and introduce stresses which could alter the clinical working time, they are heated for several hours at 100°C to reverse these effects through the recovery stage of annealing. Particle size ranges from 25 to 50 microns.

Single-composition-spherical alloys are produced by atomizing the molten alloy in a chamber filled with an inert gas such as argon. The molten metal falls through a distance of approximately 30 feet and cools as it does. This results in the characteristic spherical particle shapes. Particle size ranges from 5 to 40 microns.

Different sized spherical particles are used in formulating a single-composition spherical alloy to improve its condensation characteristics. Early sphericals did not use this method of formulation and exhibited poor condensation properties.

General Characteristics of Amalgam

- ease of manipulation
- acceptable marginal adaptation
- technique insensitivity
- self sealing
- biocompatible
- good wear resistance
- low cost

Physical Properties of Amalgam

Dimensional Change

--in the first 30 minutes after amalgam is triturated, mercury diffuses into the silver and tin particles and, to a slight extent, they dissolve in the mercury; as a result a small amount of contraction occurs

--expansion follows as crystallization of the new phases begins; the expansion is caused by the outward thrust of the growing crystals

--whether the alloy exhibits a net contraction or expansion depends on several factors: (1) the specific alloy being used (single-composition spherical alloys contract more than single-composition lathe-cut or admixed ones); (2) condensation technique (the more mercury expressed from the alloy, the more it will contract), and trituration time (overtrituration causes contraction)

--most high-copper amalgams undergo a net contraction

--is limited by ADA Specification No. 1 to ± 20 microns/cm measured between 5 minutes and 24 hours after trituration

Strength

--strength develops slowly, taking 24 hours or longer to reach a maximum; by 1 hour, most alloys have achieved from 40% to 60% of their 24-hour compressive strength (e.g., Tytin 45% and Dispersalloy 51%); by 24 hours, most alloys have reached 90% or more of their final strength

--amalgam is considered a brittle material with much higher compressive strength than tensile or shear strength; compressive strength is 7 times that of tensile strength

--is weak in thin sections; unsupported edges fracture easily; a 90° butt joint yields maximum strength while a 70° angle of amalgam at the margins yields only 50% strength

--if loaded rapidly, amalgam will fracture quickly; if loaded slowly, it will deform somewhat prior to fracture

--spherical alloys not only harden faster but are stronger in compression than lathe-cut alloys; they are harder because they require less mercury during trituration so less of the weak

matrix portion forms

--must have a minimum 1-hour compressive strength of 11,600 psi (80 MPa) as required by hour as specified by ADA Specification No. 1

Plastic Deformation (Creep)

--creep is the time dependent response of an already hardened material to stress; the response is one of plastic deformation and may be static or dynamic depending on the stress involved; creep occurs near the melting temperature of the material (on the Absolute scale)

--occurs with amalgam because gamma 1 and 2 are functioning at 78% and 94% of their melting temperatures (on the Absolute scale) at oral temperatures

--occurs due to slippage of grain boundaries of gamma-1 particles; the particles "slide" across each other

--gamma 1 also facilitates creep because it is a fine-grained structure with grain size of about 2 microns; this produces a great deal of grain boundary slipping

--creep is detrimental to amalgam because it causes amalgam to flow out over margins where the thin amalgam fractures; this results in marginal deterioration or "ditching"

--the association between static (and dynamic creep) and marginal deterioration was first demonstrated by Mahler et al²⁵

--is higher when the gamma-2 phase is present because gamma 2 is plastic and allows gamma-1 slippage

--high-copper alloys reduce creep in two ways: copper ties up the tin preventing tin-mercury (gamma 2) from forming; and copper ties up the tin, forming Cu₆Sn₅ (eta phase), whose crystals interlock and prevent slippage at gamma-1 grain boundaries

--a net copper concentration >12% is required to eliminate the gamma-2 phase

--any factor that acts to increase residual mercury levels increases creep; a delay between trituration and condensation increases residual mercury and therefore increases creep; increased condensation pressures reduce residual mercury and therefore reduce creep

--marginal areas always have higher levels of residual mercury

--is limited to 3% by ADA Specification No. 1

--creep is not as significant an indicator of the tendency for high-copper amalgams to undergo marginal deterioration as it is for low-copper amalgams because the former exhibit creep rates under 1% and these rates result in clinically insignificant amounts of marginal deterioration

Corrosion

--while corrosion is capable of reducing the strength of a restoration by 50% in five years, a beneficial aspect of corrosion is that the by-products that form act to seal the cavity margin

--low-copper amalgams form corrosion products of tin oxides and tin chlorides at both the tooth/amalgam interface (to seal the margins and prevent leakage)²⁶ and in the interior of the amalgam; the most corrosion-prone phase in these alloys is gamma 2 (Sn₈Hg)

--high-copper amalgams form corrosion products similar to those formed by the low-copper alloys (tin oxides and tin chlorides); in addition they form copper chloride;²⁷ they corrode slower than low-copper amalgams; it takes from 6 months to 2 years²⁸ for high-copper alloys to self-seal their margins because they contain little or none of the most corrosion-prone phase, gamma 2; the most corrosion-prone phase in high-copper amalgams is the eta phase (Cu₆Sn₅);²⁹

--evidence indicates that zinc may reduce marginal fracture by preferentially corroding instead of tin in the eta phase; this reduces the rate of marginal corrosion and deterioration

Thermal Conductivity

--amalgam transmits temperature changes readily to the pulp because of its relatively high thermal conductivity

Coefficient of Thermal Expansion

--the value for amalgam is 2½ times that of dentin; this difference promotes microleakage

Microleakage of Amalgam

--factors that promote microleakage

---the 2- to 20-micron-wide gap that always exists between the amalgam and tooth structure

---poor condensation techniques that result in marginal voids

---a lack of corrosion by-products necessary to seal the margins

---a coefficient of thermal expansion for amalgam which is 2½ times greater than the coefficient for tooth structure

---use of single-composition-spherical alloys which leak more than lathe-cut or admixed alloys;^{21,30} this may be because they do not adapt as well to the margins of the preparation³¹

Selecting a Type of Amalgam

--the most important information upon which to base the selection of an alloy is long-term clinical results

--no evidence exists that creep is a predictor of clinical performance for high-copper amalgams; the reason is that creep rates for these alloys are much less than 1% and, at these low levels, creep does not result in clinically significant marginal deterioration

--strength is probably the least important characteristic because all commercially available amalgams easily exceed the minimum requirement found in ADA Specification No. 1³²

--a selection should also be based on the handling characteristics that the clinician wants; for instance:

*spherical alloys

+advantages: are easier to condense into areas of difficult access (such as around pins) because they provide less resistance to condensation pressures; they harden rapidly; are smoother for carving, burnishing, and polishing

-disadvantages: are difficult to achieve tight interproximal contacts with because of their "plashy" nature

*lathe-cut alloys

+advantages: are easier to achieve tight interproximal contacts with because they resist the forces of condensation well

-disadvantages: are more difficult to condense into areas of difficult access (such as around pins) because they provide greater resistance to condensation pressures; they harden more slowly than spherical alloys which means a greater chance of marginal ridge fracture during matrix band removal; are not as smooth for carving, burnishing, and polishing

*admixed alloys

have the advantages of spherical alloys but not their disadvantages; have the "body" of lathe-cut alloys when condensing; are easily condensed with good adaptation

Trituration

--the purpose is to remove oxide layers from the alloy particles, to coat each alloy particle with mercury, and to provide a homogeneous mass for condensation

--manufacturers provide a range of recommended trituration times for each alloy; the time needs to be adjusted depending on the triturator being used

--signs of a good mix: a shiny, homogeneous mass that

adheres together

--undertrituration (i.e., triturating for shorter than the recommended time) results in a crumbly mix that is very weak; it decreases tensile and compressive strength values (for spherical alloys) and increases creep; never undertriturate

--overtrituration (i.e., triturating for longer than the recommended time) results in a mix that is warm and has a dull surface; often the mix sticks to the capsule; it shortens setting time (because the amalgam mass becomes heated), increases contraction, and increases creep; also increases tensile and compressive strength values (for lathe-cut alloys), decreases tensile and compressive strengths (for spherical alloys); overtrituration by 10% is acceptable

One study has found that substantial changes in trituration times have the potential for causing statistically significant changes in the compressive strengths for high-copper amalgams.³³ The changes did not, however, result in strengths below those suggested to be the minimum required for clinical success (310 Mpa or 45,000 psi). Creep rates were also found to be significantly altered but were still well below the 1% level which represents clinical significance.

One way of determining the proper trituration time for a brand of amalgam:

- set the frequency as recommended by the manufacturer
- set the mixing time 6 seconds shorter than that recommended by the manufacturer
- triturate the capsule and examine the mixed amalgam
- increase the time incrementally by one second and make a test mix; when the first plastic mix is produced, increase the time by two seconds and use this as the mixing time

The frequency (i.e., cycles per minute) at which the amalgam is triturated can also have affect the alloy. One study³⁴ found that alloys which contain lathe-cut particles (e.g., single-composition lathe-cut amalgams and admixed amalgams) will have their working times (i.e., the time available for condensing and carving) significantly reduced when triturated at too high a frequency. A lengthening of working time is seen if trituration at too low a frequency occurs.

Condensation

Objectives:

- to adapt amalgam to the walls and floors of the preparation, around pins, etc.
- to eliminate voids in the amalgam mass
- to remove excess mercury which leads to a stronger

restoration

Rules of Condensation:

- have a constant supply of amalgam
- constantly condense
- condense laterally as well as apically
- condense with adequate force

Condensation depends upon:

- plasticity of the mass
- size of the amalgam increment: a larger mass will dissipate forces at a shallower level of the mass which can result in incomplete condensation and a layering of the alloy increment
- condenser size: the smaller the condenser face, the greater the force
- direction of force
- amount of force
- when condensing spherical alloys, use larger condensers because smaller ones will displace the spherical particles rather than condense them
- it is important during condensation to constantly condense, to condense laterally as well as apically, and to condense with adequate force
- admixed alloys generally require 8 to 10 pounds of force for proper condensation and most practitioners only exert 3 to 4 pounds
- the entire mass should be condensed within 3½ minutes from the start of trituration

Carving

- it is best to overpack the cavity preparation and carve to the margins in order to reduce the mercury-rich surface layer
- occlusal anatomy should be kept somewhat shallow to preserve bulk of the alloy at the margins; you do not want an acute angle of amalgam at the margins
- some operators advocate a two-step burnishing technique; the initial burnishing is done following condensation and helps to improve marginal integrity; the second burnishing is done after carving to reduce surface roughness
- burnishing has also been shown to reduce leakage;^{35,36} pre- and post-carve burnishing together are more beneficial in reducing leakage than is pre-carve or post-carve burnishing alone³⁷
- some clinicians avoid burnishing because they believe it draws mercury to the surface of the restoration, however this has not been shown to be the case
- increasing the percentage of spherical particles in the

alloy improves carvability and polishability

Finishing and Polishing

Benefits of Polishing:

- improves marginal adaptation by removing flash
- reduces tarnish and corrosion (especially concentration cell corrosion)
- helps to facilitate plaque control because the surface is smoother and easier to clean
- polishing may not be necessary for small restorations of high-copper alloys because they tend to be self-polishing
- one study found no significant difference in marginal integrity between polished and unpolished high-copper amalgam restorations³⁸
- another study found no significant difference in marginal quality between unpolished, immediately polished, and 24-hour polished amalgam restorations³⁹

Polishing Procedure:

- begin with a pre-carve burnishing; this is really an extension of condensation which removes mercury from the surface
- follow with initial carving and removal of the matrix
- perform final carving
- do post-carve burnishing
- you must burnish the amalgam before it is set; if it looks shiny during burnishing, the burnishing is probably not doing much good because the amalgam has already set
- use a small instrument (e.g., ball burnisher, Dycal applicator) and apply light pressure down the margins and in the grooves
- Leinfelder has proposed that this burnishing is a useful step if you do not intend on polishing the restoration
- following post-carve burnishing, use a prophylax cup with prophylax paste to lightly polish the restoration; this gives it a smooth matte finish which helps to reduce the time necessary at a future appointment for polishing

Be aware of the need to use light pressure with rubber points and cups because they can otherwise generate heat. If the temperature of the amalgam exceeds 140°F, the pulp may be injured and mercury will leach to the surface of the restoration leaving the marginal areas mercury-rich. This can result in more marginal ditching and fracture. A water coolant is always advised when polishing and finishing amalgam restorations.⁴⁰

References

1. Innes DBK, Youdelis WV. Dispersion strengthened amalgams. J Can Dent Assoc 1963;29:587-593.

2. Phillips RW, Swartz ML, Boozayangool R. Effects of moisture contamination on compressive strength of amalgam. J Am Dent Assoc 1954;49:436-438.
3. Yamada T, Fusayama T. Effect of moisture contamination on high copper amalgam. J Dent Res 1981;60:716-723.
4. Osborne JW, Howell ML. Effects of water contamination on some properties of high copper amalgam. Am J Dent 1994;7:337-341.
5. Osborne JW, Berry TG. Zinc-containing high copper amalgams: A 3-year clinical evaluation. Am J Dent 1992;5:43-45.
6. Johnson GH. A laboratory evaluation of two new dental amalgam alloys [Abstract]. J Dent Res 1985;64:277.
7. Johnson GH, Bales DJ, Powell LV. Clinical evaluation of high-copper amalgams with and without admixed indium. Am J Dent 1992;5:39-42.
8. Johnson GH, Bales DJ, Powell LV. Effect of admixed indium on the clinical success of amalgam restorations. Oper Dent 1992;17:196-202.
9. Powell LV, Johnson GH, Bales DJ. Effect of admixed indium on mercury vapor release from dental amalgam. J Dent Res 1989;68:1231-1233.
10. Youdelis WV. Effect of indium on residual mercury content and compressive strength of amalgam. J Canad Dent Assoc 1979;45:60-62.
11. Youdelis WV. Effect of indium on dispersion-type amalgam. J Canad Dent Assoc 1979;45:64-66.
12. Nakajima H, Awaiwa Y, Hashimoto H, Ferracane JL, Okabe T. Surface characterization of amalgam made with Hg-In liquid alloy. J Dent Res 1997;76:610-616.
13. Townsend JD, Hamilton AI, Sbordone L. Biologic evaluation of a silver-copper-germanium dental casting alloy and a gold-germanium coating alloy. J Dent Res 1983;62:899-903.
14. Townsend JD, Hamilton AI, Sbordone L. Biologic evaluation of an amalgam containing indium and two germanium-containing alloys for cast prostheses [Abstract]. J Dent Res 1983;62:221.
15. Mahler DB, Engle JH, Adey JD. Effect of Pd on the clinical performance of amalgam. J Dent Res 1990;69:1759-1761.
16. Mahler DB, Nelson LW. Factors affecting the marginal leakage of amalgam. J Am Dent Assoc 1984;108:51-54.
17. Mahler DB, Nikutowski EA. Factors relating to the microleakage of amalgam restorations [Abstract]. J Dent Res 1989;6:189.
18. Mahler DB. The amalgam-tooth interface. Oper Dent 1996;21:230-236.
19. Johnson LB. Comparative rate of amalgam formation from tin, silver and dental alloy powders. J Dent Res 1967;46:753.
20. Rupp NW, Paffenbarger GC, Patel PR. Effect of residual mercury content on creep in dental amalgams. J Am Dent Assoc

1980;100:52-55.

21. Mahler DB, Bryant RW. Microleakage of amalgam alloys: an update. *J Am Dent Assoc* 1996;127:1351-1356.
22. McCabe JF. *Applied dental materials*. 7th ed. Oxford:Blackwell Scientific Publications, 1990, p 135.
23. Swartz ML, Phillips RW. Residual mercury content of amalgam restorations and its influence on compressive strength. *J Dent Res* 1956;35:458-466.
24. Okabe T. Mercury in the structure of amalgam. *Dent Mater* 1987;3:1-8.
25. Mahler DB, Terkla LG, Van Dysden JV, Reisbick MH. Marginal fracture vs mechanical properties of amalgam. *J Dent Res* 1970;49:1452-1457.
26. Swartz ML, Phillips RW. In vitro studies of the marginal leakage of restorative materials. *J Am Dent Assoc* 1961;62:141-151.
27. Andrews JT, Hembree JH, Jr. Marginal leakage of amalgam alloys with high content of copper. *Oper Dent* 1980;5:7-10.
28. Sutow EJ, Jones DW, Hall GC, Owen CG. Crevice corrosion products of dental amalgam. *J Dent Res* 1991;70:1082-1087.
29. Marshall SJ, Marshall GW. Dental amalgam: the materials. *Adv Dent Res* 1992;6:94-99.
30. Mahler DB, Nelson LW. Sensitivity answers sought in amalgam alloy leakage study. *J Am Dent Assoc* 1994;125:282-288.
31. Fayyad MA, Ball PC. Cavity sealing ability of lathe-cut, blend, and spherical amalgam alloys: a laboratory study. *Oper Dent* 1984;9:86-93.
32. Marshall GW, Marshall SJ. Dental amalgams: phase relations. In: Bever MB, editor. *Encyclopedia of materials science and engineering*. Oxford (UK):Pergamon Press, pp 1051-1056.
33. Murchison DF, Duke ES, Norling BK, Okabe T. The effect of trituration time on the mechanical properties of four high-copper amalgam alloys. *Dent Mater* 1989;5:74-76.
34. Brackett WW, Swartz ML, Moore BK, Clark HE. The influence of mixing speed on the setting rate of high copper amalgam. *J Am Dent Assoc* 1987;115:289-292.
35. Kato S, Okuse K, Fusayama T. The effect of burnishing on the marginal seal of amalgam restorations. *J Prosthet Dent* 1968;19:393-398.
36. Chan KC, Edie JW, Svare CW. Scanning electron microscope study of marginal adaptation of restorative finishing techniques. *J Prosthet Dent* 1977;38:165-168.
37. Ben-Amar A, Serebro L, Gorfil C, Soroka E, Liberman L. The effect of burnishing on the marginal leakage of high copper amalgam restorationsfs. An vitro study. *Dent Mater* 1987;3:117-120.
38. Mayhew RB, Schmeltzer LD, Pierson WP. Effect of polishing on the marginal integrity of high-copper amalgams. *Oper Dent*

1986;11:8-13.

39. Collins CJ, Bryant RW. Finishing of amalgam restorations: a three-year clinical study. J Dent 1992;20:202-206.

40. van Amerongen JP, Penning C. Temperature changes during the finishing of amalgam restorations. J Prosthet Dent 1990;64:455-458.