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Metal Fusion and Granulation

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METAL FUSION
AND GRANULATION

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INTRODUCTION

As a student of metalsmithing, I have frequently encountered brief and incidental references in texts and articles to a technique used for surface enrichment. Illustrations of this technique are to be found in texts which contain treasures of ancient worlds. Real artifacts demonstrating this technique can be seen in museums, such as the Metropolitan Museum of Art in New York City. Having confronted such examples of this technique, but lacking information concerning its execution, I became intrigued by and immensely interested in investigating its properties. The technique to which I refer is granulation by surface fusion.

The description of granulation has always been quite simple, but the execution has been something of a mystery. The ancient Etruscan craftsmen appear to have been reluctant to reveal their secrets of granulation, as no records of their methods have been discovered to this day. Attempts were made to record the Roman and somewhat later methods of granulation; but, these have been found incomplete. Thus, later generations actually rediscovered this technique for surface enrichment, though not all rediscovered methods are the authentic Etruscan process of metal fusion.

The ancient craftsmen of necessity overcame tremendous handicaps and obstacles to achieve granulation by metal fusion. It is interesting to note that with our superior tools, exacting control over electrical heat and advanced scientific knowledge few craftsmen today have sufficient skill to compete with the Etruscan's mastery of this process. Also noteworthy is the possibility that the pieces of ancient jewelry which have come down to us as examples of granulation are not the finest examples of the period. The finest pieces would have been placed in tombs, palaces and state treasure houses, according to social custom, and they were undoubtedly the first to be confiscated and melted by invaders and grave robbers. Hence, even finer examples of these craftsmen's skills probably existed.

Through research I have discovered that most recorded evidence of granulation has been on a metal base of gold. The existing methods and composition formulas pertain primarily to gold. The most commonly used method of granulation today, and probably the same as the one employed by the ancient craftsmen, is by an English metallurgist and goldsmith, H. A. P. Littledale. Littledale's patented method with some variations is currently used by craftsmen on gold. I propose to modify existing processes of granulation by surface fusion for use on a metal base of sterling silver.

The purpose of this thesis is to investigate, develop and execute the most efficient techniques of metal fusion and granulation and to utilize these techniques to enhance the surfaces of a sterling silver teapot warmer.

GLOSSARY OF TERMS

Capillary attraction: "a force that is the resultant of adhesion, cohesion, and surface tension..."

Colloid: "a gelatinous substance made up of very small, insoluble, nondiffusible particles larger than molecules but small enough so that they remain suspended in a fluid medium without settling to the bottom..."

Fuse: "to make or become liquid by great heat; melt."

*Fusion: "a fusing; melting or melting together; the union of different things by or as if by melting."

Granulate: "to form into grains or granules..."

*Granulation: "formation into granules or grains..."

Granule: "a small grain..."

Pallion: "a small piece; a bit; a pellet."

Solder: "a metal alloy used when melted for joining or patching metal parts or surfaces; figuratively, anything that joins or fuses; bond..."[1]

*Granulation, by definition, refers only to the formation of spheres or granules and not to the manner in which the spheres or granules may be adhered to a metal base. Metal fusion, however, is an intrinsic part of the total process of granulation as it is the method whereby the spheres are bonded to a metal base. Throughout this thesis, the term granulation will, of necessity, refer to and include the process of metal fusion.

CHAPTER I

THE HISTORY OF GRANULATION

Examples of granulation are first found in Western Asia, dating from around 2000 B. C. These early artifacts displaying granulation were discovered in Minoan tombs on the Isle of Crete. Craftsmen of this Aegean culture found that a small amount of very finely divided copper brought into contact with heated gold lowered the melting point of the metals. The two surfaces then combined to make a sound joint. This discovery enabled them to produce filigree and granulated surface decorations.

The originators of the granulation processes cannot be identified as belonging to any one distinct culture. Evidences of granulation appear from many cultures around the same period; one granulated necklace was found in the tomb of an Egyptian princess dating back to 1920 B. C.

The finest examples of gold granulation were produced by the Etruscan goldsmiths between the eighth and second centuries, B. C. The Etruscan civilization soon came into contact with the expanding Greek civilization. The Greek craftsmen reproduced granulation in a slightly less refined manner than that of the Etruscans. The Roman craftsmen, influenced by both Etruscan and Greek cultures, employed granulation which could be described as coarse and sparse. Pliny, who died in A. D. 79, recorded valuable information concerning Roman methods of surface fusion. Granulation passed from common use as a means of surface enrichment with the fall of the Roman Empire.

The next recorded evidence of granulation processes occurs in the twelfth century. Theophilus, a monk, produced an account of the granulation methods employed by the craftsmen of his day. During the Middle Ages granulation apparently became a lost art as no recorded evidence of artifacts are in existence today.

In the nineteenth century attempts were made to revive granulation by surface fusion. The difficulty lay in the method of attaching the granules.

> The nineteenth-century jeweller, Castellani, tried, without success, to achieve the desired results by normal methods of soldering; but the solder always flooded and the flux boiled up and displaced the grains.[2]

In this century there have been various fairly satisfactory methods of adhering granules to a metal base by the use of solder. All these methods, however, are extremely tedious and sacrifice the individual spherical shape of the granules. The ancient craftsmen could not have successfully employed these adhering methods as evidenced by the poor quality of their soldered joints.

After World War I, a German metallurgist, Marc Rosenberg, was also exploring the processes of granulation. He found that granulation by metal fusion could be accomplished with the use of carbon as a bonding agent. This discovery led to further understanding of the necessary procedures and physical properties involved in refining this technique and contributed to H. A. P. Littledale's patented process.

> In 1933 Littledale patented a new process of hard-soldering which he entitled, "Colloid hard-soldering". Using this process (one well within the powers of an ancient craftsmen) he succeeded in reproducing exactly some of the most complicated of the surviving pieces of ancient filigree and granulation. There can, in fact, be no doubt that this process, or something very like it, was employed in antiquity. Indeed, both Pliny and Theophilus show echoes of it, but Pliny's version is so garbled as to be unworkable, and Theophilus is not entirely comprehensible.[3]

One of the leading contemporary craftsmen to master the difficult processes of granulation is Professor Elisabeth Treskow of Cologne, Germany.

She is one of the finest craftsmen produced by the European Guild System, and she uses this surface enrichment with unparalleled perfection and skill. Another contemporary craftsman, an American goldsmith, John Paul Miller, has further developed Littledale's basic principle of granulation; however, Miller has preferred to reveal only those techniques which are most evident and already shared by most craftsmen today.[4]

CHAPTER II

PREPARING THE GRANULES

Construction of the granules used in granulation is the first step in the total process. Various theories exist for making granules, but most of them are far too laborious for the large quantity of granules required to adorn one article. The simplest technique for making one granule is to:

> ...put a tiny fragment of silver or gold on a charcoal block and allow the tip of the bright blue flame from the torch to touch it, it will melt instantly and run up into a ball or grain.[5]

This granule will be slightly flattened from resting on the charcoal while cooling. In order to create truly spherical granules, small concave depressions, one half the desired size, can be carved into the charcoal block. The small pallion of metal is then laid over each depression and when heated melts and falls into the mold. Another method of creating a small number of granules is to individually heat the metal pallion on a charcoal block and while in a molten stage pour it into a cup containing a small wad of cotton submerged in linseed oil. These methods are extremely time consuming when one considers the small quantity produced. But these methods can be of value in testing and determining individual granule size.

The processes used by ancient craftsmen for the formation of granules may have been more complex. Modern experts theorize about the probable methods used in antiquity. Three such probable methods relate that:

> ...molten metal was made to pass through an extremely fine sieve, or that the golden wire was melted until it became possible to transform it into small particles, which could be picked up and made even finer by rolling them between two plates of metal or glass. A third, and more acceptable theory, based on experiments made in Valencia, is that gold dust, mixed with adhesive borax, was scattered upon the red-hot metal bar or plate.[6]

The most satisfactory and efficient methods of producing large quantities of granules are similar in principle and procedure.

> Small pieces of gold of roughly equal size are laid separately in a clay crucible on a bed of powdered charcoal, and alternate layers of gold and charcoal are built up until the crucible is full. It is then brought to a bright red heat, which melts the gold into minute spheres, separated from each other by the charcoal.[7]

One hazard in utilizing this method is the clay crucible which does not withstand repeated temperature changes and fractures after several firings. A second and similar method of preparing granules is the one in which:

> ...a high, rather narrow crucible must be used.

> Powdered charcoal is first placed in the bottom of the crucible to the depth of at least ½". Over this is placed a loosely sifted layer of filings or wire snippets. Another layer of charcoal is followed by more metal particles and so on until the crucible is filled.
>
> The filled crucible is placed in a muffle furnace and heated to at least 1900° F.[8]

The use of a high, rather narrow crucible inhibits the capillary attraction of the granules because their own weight, when stacked, causes them to combine. If a wider, more shallow crucible is used the granules remain separate and retain their individual form; thus, gravity is an important factor in the formation of granules. The gravitational pull can also cause the granules to sink and combine if they come into contact with the floor of the container. In order to assure the successful formation of the granules and to prevent their contacting the container, a ¾" layer of powdered charcoal should be used rather than just a ½" layer. The layers of charcoal act as insulators and maintain a uniform intensity of heat throughout the suspended granules. The temperature range for successfully forming silver granules is between 1750° F. and 1800° F. for a period of ten to twenty minutes, depending upon the size of the container. The above mentioned temperature of 1900° F. is necessary for the formation of gold granules.

The actual granule formation occurs in this way: the metal pallions which are suspended in the powdered charcoal react to the force of capillary attraction when the proper temperature is reached and maintained for the necessary period of time. The granules, when removed from the container, are free from oxidation as a result of the reducing atmosphere created by the charcoal.

Considering these physical phenomena which occur in the formation of silver granules, the following procedures are those which I have found most effective and efficient. A very necessary first step is that of cleaning the metal to remove all firescale or oxidation prior to cutting the pallions. The metal should then be rolled to a thickness of thirty to thirty-six guage and cut into small pallions; the size of the pallions determines the size of the granules. Fig. 1. This method is most efficient for forming small granules of approximately 1/16", or smaller, because larger size pallions succumb to gravitational pull rather than capillary attraction, thus, failing to become

Fig. 1 Cutting the pallions.

Fig. 2 Cutting the jump rings.

spherical. For forming granules larger than 1/16", coiled wire which is cut into individual jump rings should be used. Capillary attraction causes the ends of these jump rings to retract into perfectly formed granules. Fig. 2. The pallions which have been formed by cutting sheet stock or coiled wire are sprinkled (without touching one another) onto a ¼" layer of powdered charcoal at the bottom of a container. The container can be made of any material which will withstand the necessary temperatures, and a coffee can provides a perfectly satisfactory container. Fig. 3. The initial layer of pallions must be covered with at least a ¼" layer of powdered charcoal. Additional layers of pallions, each with a ¼" charcoal cover, can extend to the top of the container.

The container is placed into either a gas or an electric kiln which is preheated to 1800° F. and equipped with a pyrometer to control and maintain the proper temperature. Fig. 4. The container should remain at 1800° F. for ten to twenty minutes depending on the size of the container. The granule development can be tested by removing the container

Fig. 3 Coffee can container with pallions.

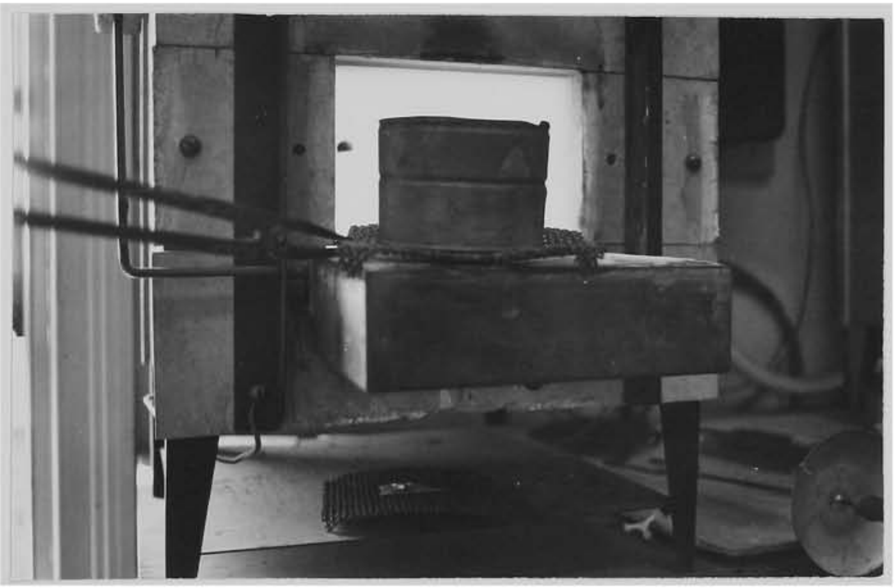


Fig. 4 Placing container into a preheated kiln.

from the kiln and extracting, with tweezers, a small amount of charcoal containing the granules. The charcoal is then dropped into cool water through which the granule maturity can be observed. The container can be reheated if continued capillary attraction is necessary. When the granules have reached maturity in the container they should be removed from the kiln and allowed to cool slowly. Fig. 5. Water can then be added which will wash away the charcoal, leaving the granules at the bottom of the container. Fig. 6. Detergent may be added to further clean the granules. Sieves may also be employed to size the dried granules according to their individual diameters. Fig. 7.

Fig. 5 Container cooling slowly.

Fig. 6 Washed granules.

Fig. 7 Sizing granules.

CHAPTER III

DECORATIVE APPLICATIONS

Granulation, when competently used, heightens the splendor of any surface of metal through the interplay of tone qualities. Various procedures exist for applying the granules to a metal surface. The direct method of applying each individual granule to the metal base is the most tedious but probably the most individual means of expression. Each granule is put in place with the aid of a colloid solution and a small brush or tweezers. A similar method is to first apply the colloid solution to the metal base in the pattern desired and then to sprinkle the granules over the entire piece; the granules will adhere only to the areas which have been coated with the solution.

In antiquity, the transfer method of applying the granules is the method that most likely was employed. The transfer method facilitates the application of great numbers of granules, which is characteristic of the period. In this method:

> ...the pattern is first engraved on a plate of stone or metal, and the grains are set in the engraved areas. A drum is made by sticking a sheet of paper over the end of a tube; in antiquity papyrus or leather would have served. The paper is covered with an adhesive and is lowered on to the engraved plate to pick up

> the grains, which are treated with a soldering mixture and placed on the surface to be decorated. The paper is now soaked off and the work is ready for soldering.[9]

The advantage of this method is that the same pattern can be repeated as often as required.

Many decorative possibilities of granulation exist. Granules which may vary in size from 1/200th of an inch to ¼" in diameter create various levels of low relief. In addition to providing relief, the granules may be massed to cover an entire piece, to cover only portions of the piece (Fig. 8), to form linear patterns, or to create geometric shapes. Fig. 9.

Even more elaborate styles of granulation exist. The outline style employs the granules in lines around an embossed form or area. Fig. 10. In the silhouette style, figures and shapes are rendered with solid masses of granules. Fig. 11. The reverse of the silhouette style is possible if the solid masses of granules form the negative areas, leaving the main figures or shapes undecorated. Thus, granulation presents infinite possibilities for surface enrichment and does challenge the craftsman's imagination and skill.

Fig. 8 Etruscan granulation of the massed style.

Fig. 9 Etruscan granulation of the linear style.

Fig. 10 Etruscan granulation of the outline style.

Fig. 11 Etruscan granulation of the silhouette style.

CHAPTER IV

TECHNIQUES OF GRANULATION

The ancient craftsmen overcame tremendous obstacles and handicaps to achieve granulation. These early craftsmen had no optical aids, such as magnifying glasses or lenses, to enable them to view the granule fusion. Historians relate that ancient craftsmen:

> ...employed children for this work, and it is said that their eyesight was usually permanently damaged by the age of ten or twelve.[10]

The obstacles and handicaps were technical, as well as physical. The only means which these craftsmen had of heating metal was, at best, a charcoal brazier. A brazier would give adequate heat, but this heat would seem to have been almost impossible to control. In spite of such obstacles, these craftsmen were completely successful in controlling the heat necessary for granulation, as can be observed in their pieces, for the slightest excess of heat would have reduced their thin guage gold stock into a blob of molten metal.

The first recorded methods of granulation occur during the latter part of the Roman Empire. Pliny notes that the Roman goldsmiths used copper carbonate derived from a copper salt and an animal hide glue. The glue is used as the carbonizing adhesive which, upon being fired, aids in fusing the granules. Using the limited information set down by Pliny, granulation on silver is not attainable; however, high karat gold granulation can be achieved with this chemical combination. The defect in this method when applied to silver appears to be the copper carbonate, which does not break down and fuse at the necessary temperature. The result of the use of this method on silver is that the silver granules fuse to the metal base, losing their spherical identity, before the copper carbonate melts.

The method recorded next occurs in the twelfth century when Theophilus describes the way in which he achieves granulation. He creates copper oxide by alternately heating and quenching a sheet of copper. The scales of copper oxide are then finely ground and mixed with an animal glue. This method is satisfactorily employed on gold but is not successful when used on silver. The heat necessary to melt the copper oxide causes the silver granules to lose their identity and also causes a characteristic "orange peel" roughness to appear on the surface due to overheating.

At the close of World War I, a German metallurgist, Marc Rosenberg, devised a method of attaching high karat gold granules through the use of a carbon compound. The carbon compound consists of India ink and a fish glue which act as a flux. The flux promotes the fusion of the gold granules at the point of contact with the metal base. The fusion occurs at a slightly lowered temperature, due to the addition of this carbon flux which has been absorbed into the metal surfaces. The advantage of a lower melting temperature than is normally required for gold is that the granules fuse only at the point of contact and remain perfectly shaped. This method with its flux preparation is not practical for use on silver because the silver does not absorb a sufficient amount of carbon to form a strong enough bond for use in jewelry. The polishing process alone dislodges many of the granules. Rosenberg's contributions, though unsuccessful on silver, do give assistance to later craftsmen exploring the granulation processes.

The next significant contributor to the fund of information concerning granulation is an Englishman, H. A. P. Littledale. While attempting to reproduce pieces of fine Etruscan jewelry, Littledale discovered that two major difficulties exist in duplicating their granulation technique. The solder, no matter how finely cut or filed, continues to flood and flow between the granules leaving little definition of the spheres. The flux boils up and displaces the granules. After long experimentation, Littledale separated the solder into its basic chemical components and, by utilizing Rosenberg's discoveries, dispensed with a borax flux in favor of carbon.

Littledale's patent refers to numerous possible combinations of oxides in colloid solutions which can be employed for fusing metals. These possible oxides include: antimony, copper, gold, lead, silver, tin and zinc. One particular colloid solution which consists of silver oxide and antimony trioxide is a successful formula for the fusion of silver. This formula, however, refers to the fusion of fine silver which is pure and melts at 1761° F., not to sterling silver which is an alloy and melts at 1640° F. The ingredient, silver oxide, is a form of fine silver and does not melt at a sufficiently low temperature to fuse with sterling silver; the antimony trioxide provides an alloy which will lower the temperature at which the sterling silver and silver oxide fuse. Thus, the proportion of antimony trioxide must be increased when using Littledale's formula on sterling silver. Such modifications of his formulas are necessary in order to create the fusion conditions for sterling silver.

The following ingredients are my modifications of Littledale's formulas for colloid solutions:

1. copper carbonate - 20%
   antimony oxide - 80%
   animal glue

2. copper oxide - 20%
   antimony trioxide - 80%
   white glue

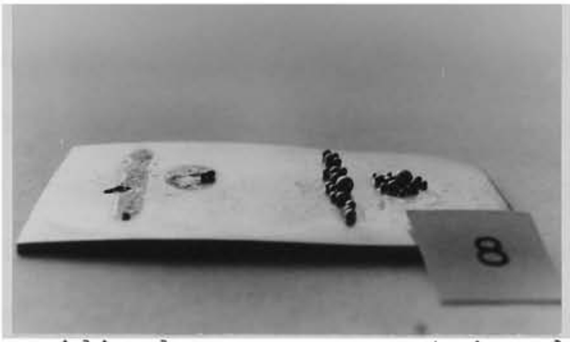
3. antimony trioxide - 60%
   silver oxide - 40%
   animal glue

4. antimony trioxide - 80%
   silver oxide - 20%
   white glue

5. antimony trioxide -100%
   white glue

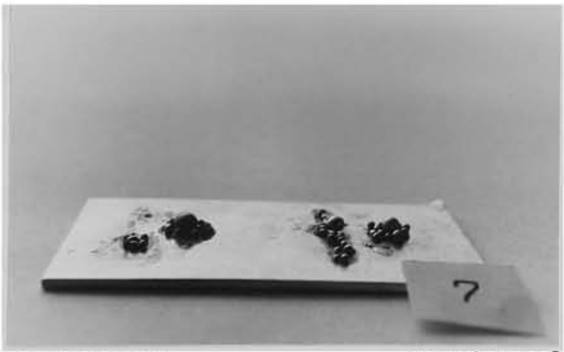
The results of the use of these formulas appear on two sterling silver surfaces, one oxidized and polished, and the other stripped of oxidation by means of a nitric solution. The granules also appear in two different arrangements, a line and a cluster, the latter of which is structurally stronger. Thus, each formula can be evaluated by its individual ability to fuse on the two surfaces and in two arrangements. Formula Number One, containing copper carbonate, antimony oxide and animal glue, fails to create a strong bond and fails to fuse the granules. Fig. 12. The high temperature necessary creates an "orange peel" surface texture, and some discoloration results from the copper carbonate.

Formula Number Two, containing copper oxide, antimony trioxide and white glue, creates a strong bond until the piece is cleaned in a weak sulphuric acid pickle. The pickle solution dissolves the copper and weakens the bond. Fig. 13. Some



oxidized stripped

Fig. 12 Example of Formula Number One.



oxidized stripped

Fig. 13 Example of Formula Number Two.

"orange peel" texture and some discoloration also occur.

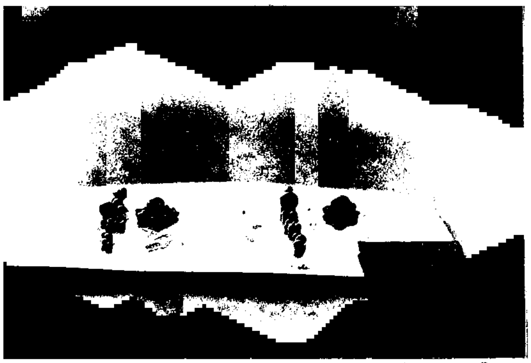
Formula Number Three, containing antimony trioxide, silver oxide and animal glue, fails to create a strong bond and fails to fuse the granules. Fig. 14. The silver oxide fails to fuse because of the low temperature necessary for sterling silver.

Formula Number Four, containing antimony trioxide, silver oxide and white glue, differs from Formula Number Three only in the proportion of oxides. This formula creates a strong bond in which the granules fuse with only a slight appearance of "orange peel" texture. Fig. 15.

Formula Number Five, containing antimony trioxide and white glue, creates a strong bond to fuse granules to the surface stripped by a nitric acid solution. Fig. 16. On a polished surface, this formula fails to create a bond. The advantage of this formula, however, is that it requires a slightly lower temperature than the previous formulas, eliminating the surface erosion. The one formula which I have developed and now employ produces a stronger bond at a lower

oxidized stripped

Fig. 14 Example of Formula Number Three.



oxidized stripped

Fig. 15 Example of Formula Number Four.

oxidized stripped

Fig. 16 Example of Formula Number Five.

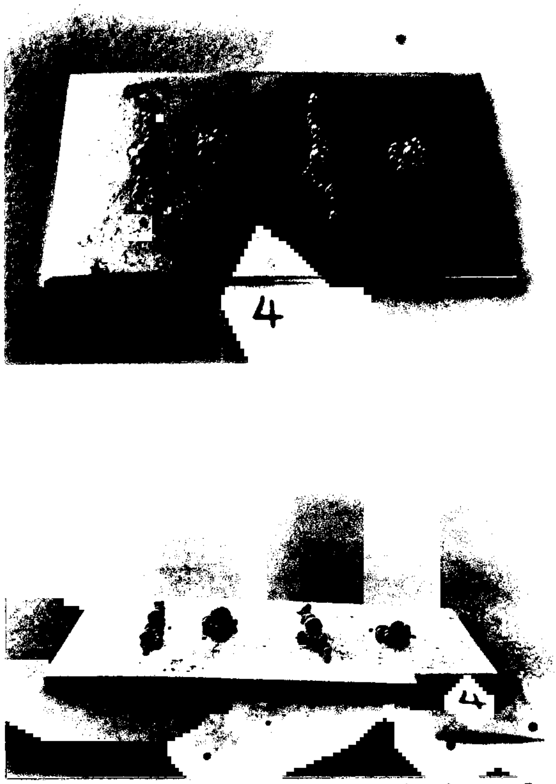
temperature than any of the first five formulas. This final formula is a variation of Littledale's basic oxide compounds to which I have added two ingredients. Fig. 17.

My formula for a colloid solution to fuse sterling silver granules contains the following ingredients:

6.	antimony trioxide	- 50%
	silver oxide	- 20%
	borax glass	- 30%
	gum tragacanth	

I discovered that finely ground borax glass is frequently used for fine soldering because it does not boil and displace the solder, as borax flux. This ingredient, borax glass, which I use in my formula is necessary because it helps to keep the sterling silver free from excessive oxidation and allows more rapid fusion. A second ingredient, gum tragacanth, is necessary as an adherent, and is advantageous because of its high carbon content. The carbon absorbs the oxides during the fusion process. The gum tragacanth is water soluble, which enables repeated use of the same solution simply by adding water.

The formula with the above ingredients can be



oxizided stripped

Fig. 17 Example of Formula Number Six.

used to fuse granules to either a polished and oxidized surface, or to a nitric acid stripped surface. The advantage of a formula for fusing granules to either of these surface conditions is that upon fusing some granules to a metal base, more granules can be added in a second firing. The procedure for adding more granules with other colloid solution formulas would be to first polish and clean the surface of all oxidation after each firing. The firings create oxidation which discolors the surface of the metal base and hinders the fusion process. Therefore, the oxidation has to be cleaned or removed before adding more granules. My formula facilitates the addition of more granules to a surface design at any time without requiring the tedious cleaning process and without restricting the design.

In employing any formula for granulation, a very necessary first step is cleaning and polishing the metal base. The cleaning can be accomplished by repeatedly heating and quenching the metal base in a solution of 50% nitric acid and 50% water. This stripping process removes all fire scale or oxidation and dissolves all copper from the surface of the metal, insuring a strong bond. The piece is then buffed and polished to the desired finish as buffing after granulation distorts the granules. The granules which have already been prepared (See Chapter II) are coated with the colloid solution and applied to the metal base with the use of a brush or tweezers.

When the solution is dry, the piece is ready for the fusion process. The heating of the piece is done slowly with a small reducing flame. (A reducing flame is one to which enough air has been added to remove the yellow color from the feathered tip.) As the piece heats to 212° F., the glue changes to carbon. At 400° F. the water evaporates. The carbon absorbs the oxygen in the oxides at 900° F. and passes off as carbon dioxide. Thus, the remaining element or residue is only the metal which alloys and forms the granulating bond. The fusion takes place within a temperature range of 1400° to 1800° F., depending upon the metal involved.

Sterling silver, if used as the metal base, will begin to sag or lose its shape at 1500° F., which is

140° lower than the temperature at which it liquefies. The temperature necessary for gold to sag or break down varies with its karat content. An entire gold surface, unlike sterling silver, when heated, will "crawl" as a liquid for a few moments before losing its form or shape. Thus, sterling silver breaks down or sags before liquefying on the surface, but gold liquefies on the surface before it breaks down. Because of this characteristic of gold, the fusion of gold granules is easier to observe and control than is the fusion of sterling silver granules.

The conditions necessary for the fusion of sterling silver granules are that the metal base remain solid and the bonding alloy flow, like a stream of mercury, along and around the points of contact. When the fused silver granules have cooled, the piece should be cleaned in a pickling solution containing 20% sulphuric acid and 80% water, which will remove the black or gray cuprous oxide on the surface. The piece is then rinsed in water and scratch-brushed lightly, using a brass wire wheel revolving at half the speed of a buffing wheel. While scratch brushing, a detergent and water should be used to lubricate the piece. If any additional lustre is desired, rouge may be used with a soft buffing wheel.

CHAPTER V

CONCLUSIONS

As a decorative technique, granulation has remained latent for many centuries. Our twentieth century has produced a few craftsmen whose creations demonstrate a restoration of this valuable lost process. Modern technology enables craftsmen to duplicate the ancient technique of granulation, although present methods undoubtedly differ from those used by the Etruscan masters. Craftsmen today may easily obtain desired chemical and metal compounds; they may also utilize precise and controllable heat sources, enabling successful fusion and alloying of metals. However, advanced equipment and accumulated knowledge do not, in themselves, insure successful granulation for the craftsman. The contemporary craftsman must utilize the granules in a design and a dimensional relief which will enhance his piece. He must control the torch flame used to heat the piece, and he must recognize the physical characteristics which occur at the moment of fusion. Thus, artistic skill, scientific understanding and perseverence all contribute to granulation which will enrich the craftsman's creations.

Investigation and experimentation on the known processes of granulation will increase any craftsman's skill and scientific understanding of the properties of metal. Both of these methods of research (investigation and experimentation) are necessary to some degree to achieve successful granulation. Investigation alone discloses various methods of preparing granules, but experimentation will produce the most efficient procedure for preparing sterling silver granules. (See Chapter II). Investigation reveals many known methods and formulas for gold granulation but only one published method for use on silver, and that is for use on fine silver. Experimentation can produce a modification of this known formula for use on sterling silver. (See Chapter IV). Investigation discloses many possible formulas for fusing metal with a colloid solution. Experimentation, such as I have performed on one of Littledale's colloid formulas, may reveal other colloid solution formulas.

The improvement which I consider most valuable in my formula is the reduced temperature at which fusion occurs. This temperature is approximately 1450° F. and eliminates the danger of overheating which causes "orange peel" and total melting. Another benefit of my formula is that additional granules can be added to the metal base after one firing without first cleaning the surface. By removing certain possibilities of error and certain tedious procedures, I feel my formula is more efficient than any other known formula for granulating sterling silver. The success of my formula and methods may be observed on my thesis piece. Fig. 18.

Modifications and improvements of any process are always possible. In the future I plan to simplify the application of my colloid solution formula by adding it to the sheet stock prior to cutting the pallions. The individual granule, when formed, will absorb the alloying oxides, and may then be placed on the metal base with only the addition of the gum tragacanth.

The challenges which are presented by metal fusion and granulation will continue to stimulate my energies. The knowledge and experience which

I have gained through my research and experimentation are invaluable, and the possibilities of surface enrichment by granulation are unlimited.

Fig. 18 Thesis Piece with decorative granulation.

FOOTNOTES

Number		Pages
1.	Webster's New World Dictionary, College Edition.	216, 288, 588, 589, 631, 1053, 1387
2.	R. A. Higgins, Greek and Roman Jewellery.	20
3.	Ibid.	20-1
4.	Conrad Brown, "Gold Granulation," Crafts Horizons, April, 1957.	12
5.	Herbert Maryon, Metalwork and Enamelling.	53
6.	Carlo Carducci, Gold and Silver Treasures of Ancient Italy.	XXVI
7.	Higgins.	19
8.	Robert von Neumann, The Design and Creation of Jewelry.	148
9.	Higgins.	19
10.	von Neumann.	148

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