Platinum Casting Theory and Techniques

Peter Romanofsky • Romanofsky

Platinum casting is an object whose shape is obtained by transferring liquid platinum into a cavity or mold and allowing it to freeze, thus taking the form of the void inside the mold. The mold, or flask as it is commonly called in the jewelry industry, can be prepared by first creating a wax or plastic replica of the original object, then encapsulating that wax or plastic replica in a refractory material such as investment or shell molding. Lastly, the wax or plastic replica must be lost from the refractory material by either heat, as is the case inside a burnout oven, or high pressure steam (autoclave), as is the case in shell casting.

Development of modern platinum casting

Platinum, is grayish-white in color, malleable, ductile and has an extremely high melting temperature: 3,224.3°F/1773.5°C. Only four or five other metals in existence have a higher melting point. Its hardness is 4.3, with a specific gravity of 21.37. Platinum is about twice as heavy as lead. It is the most important of a group of metals called the platinum group.

The other members of this group are:

- Ruthenium, *first discovered in Ruthenia (Carpathian Mountains section of Gallacia-Ukraine)*
- Rhodium, *discovered in 1804 by William Hyde Wollaston (1766-1824)*
- Palladium, *discovered in 1803 by William Hyde Wollaston (1766-1824)*
- Osmium, *discovered in 1803 by Smithson Tennant (1761-1815)*
- Iridium, *discovered in 1804 by Smithson Tennant (1761-1815).*

Chemically, platinum is a noble metal. It does not react to air, water, single acids or ordinary reagents. It will dissolve slowly in aqua regia (royal water), only after being alloyed down one part platinum group metals to four parts nickel or copper. It was not until the early 19th century that the aforementioned process was perfected in England. In this way platinum was first separated from other platinum group metals. For the first time in history platinum was refined to a pure state.

Platinum can be found naturally in the metallic state, often alloyed with other platinum group metals. Usually it is found in the earth in small grains. Platinum can be found in nugget form - nuggets have been found weighing as much as 21 pounds, although such finds are extremely rare. Platinum can be found all over the world, but the greatest amount of platinum is mined in South Africa. Ontario Canada is the second-largest producer of mined platinum ore, which is a by-product of nickel ore. Other leading producers of platinum are Russia, Columbia and the United States.

It is said that platinum was first discovered by the ancient Egyptians nearly 3,000 years ago. Platinum metals were probably used in alloyed forms in ancient Greece and Rome. Pre-Colombian natives used platinum in alloyed form hundreds of years ago, long before being conquered by the Spanish in the 16th century. In the beginning, the Spanish who brought this metal back to Europe had mistaken it for silver, thus dubbing it *platina,* or, "*little silver.*" At that time the metal's worth was not fully comprehended. Later it became the metal of choice for the royalty of Europe. It was first crafted into fine jewelry in 1780 at the court of Louis XVI of France. In the 1800s Russia's Karl Fabergé made remarkably beautiful and complex jewelry from platinum. This jewelry is renowned the world over. Many of the world's great jewelers, including Cartier and Tiffany, followed suit with their legendary jewels designed in platinum mountings.

Every group of human beings has developed its culture and civilization gradually. First, man knew nothing about metals and had to make everything out of stone and wood. Then man learned to use softer metals such as copper, silver and gold. Finally, man learned how to use harder metals such as iron, steel and platinum.

It is said that fire is one of man's greatest inventions. Little by little, man discovered new ways of making fire hotter and hotter. Archaeologists tell us man progressed through different periods, or ages. The first period in which man used metals to make tools was the *Bronze Age*. This era was born when man developed the ability to make a fire hot enough to melt copper-based metal ore into one solid form and then use this alloy to make tools. Later, man decided to pour this liquid copper-based metal directly into a form in order to form the shape in one step. The result was mankind's first castings. Thus, casting became one of the earliest of all metalworking methods. One of the first casting techniques was the chipping away of a mold into a large slab of stone. Liquid metal was then poured into the resultant cavity. Later, as man became more sophisticated, he learned that he could encapsulate an organic object inside sand and clay, and could then *fire it* (baking the form) until it stopped smoking. At this time he melted the metal and poured it into the form. This method is called *lost-wax casting* and has been dated as far back as 2230.

As B.C time progressed, man learned how to make fire still hotter. He invented various devices, such as bellows, to make strong winds in order to fan the flames. Man later found that coke, made from coal, burns even hotter than coal or wood. With this hotter fire man progressed into the *Iron Age*. This occurred around 1,100 years B.C.

Historically, archaeologists tell us the earliest iron implements were discovered in Egypt around 3000 B.C. It was not until the 14th century B.C. that civilization in Egypt, as well as the surrounding areas of Asia Minor, advanced into the Iron Age. Technology was confined to this area for a period of about 300 years. First appearances of iron-using cultures in Europe were found in the upper Danube region. From there it spread to Greece (about 1000 B.C.) and then on to Rome.

It was not until mankind was in the Iron Age that man could possess the heat required to melt platinum group metals in alloy form. This kind of heat is required for *smelting* platinum group ore. Once the raw material was smelted and platinum group alloys were created, only then could man begin to use platinum group metals.

Casting of iron did not automatically come with the birth of the Iron Age. The alloys produced from this early period of the Iron Age are classified today as wrought. These alloys were made by first smelting ore inside a furnace having a forced draft (a forge). The result from this is a metallic sponge filled with slag. This sponge was removed from the forge while still glowing incandescently and beaten over an anvil with heavy hammers until most of the impurities had been hammered out. The result was a metal object formed by blows with a hammer, a process now called forging.

Carbon contaminates platinum group metals and if present in the charge (molten alloy) will change the metals' characteristics. When early Iron Age man first tried to forge platinum group metals he found that the metal became brittle and cracked from blows with a hammer. Later he learned that the problem was due to the coal and coke that was thrown in with the ore.

This problem was eventually solved when it was accidentally found that by adding certain impurities, a flux formed and carried with it slag. This flux then floated to the top of the charge and separated into its own pool. When used properly, this flux pool shielded the charge from contamination and absorbed foreign particles within the charge. Carbon that was already in the charge was then burned out by forcing preheated air through the charge.

It was not until the 1800s that platinum group metals were first separated by means of aqua regia. This method of refining removes all impurities from the platinum to achieve four nines purity. It was also during this era that bottled gases were first introduced. This technology set the stage for platinum casting to fully come of age. Torches did, however, exist before bottled gases. A torch of this variety is still in use today in China, wherein a distilled flammable liquid is held within a container, subsequently vaporizes and is mixed with air flowing from a bellows. This type of torch cannot sustain temperatures hot enough to melt platinum.

With these technological advances, mankind has progressed to the platinum age. Platinum can be compared with the Iron Age as gold and silver can be compared with the Bronze Age. This association is based on the melting temperatures and conditions required for each respective metal.

Toward the turn of the 20th century, bottled gases were at the state at which they are today. Acetylene gas, which up until World War I was also used for illumination (automobile headlamps used acetylene gas as a fuel), was the most common gas available in bottled form. This was because acetylene can be dissolved in liquid acetone while under pressure. In this form it is much less hazardous and less likely to explode.

Hydrogen gas produces the hottest flame of all bottled gases. Hydrogen can be regulated to 30psi, which is double that of acetylene. This makes it ideal for melting and stirring platinum very quickly. It is important to note that hydrogen is highly explosive and must be treated with respect.

Modern, up-to-date methods include plasma-arc torches and induction melting, where electricity is used to heat and melt platinum. These new methods are much safer and require much less experience on behalf of the caster. The level of skill involved in operating a torch and using the flame to stir the molten platinum to a uniform temperature is quite high. The learning curve is drastically reduced by a factor of years verses days because of the new methods.

Induction melters come in three different frequency ranges::

- High frequency, 100Khz to 2Mhz and above
- Medium frequency, 10Khz to 100Khz;
- Low frequency, less than 10Khz down to line current.

Induction melters utilize one of four different technologies:

- Motor generator, low frequency
- Spark gap, high frequency
- Electron tubes, high frequency
- Solid state transistors and thyristors, low to medium frequency.

Induction is by far the best way to melt platinum. Medium frequency is the frequency range of choice and solid state field effect transistors are the most efficient devices available at present. The advantage of medium frequency is that it mixes as well as melts the platinum. This can be measured by observing the reverse meniscus of the charge rise when the induction is on and the metal is in a molten state.

Platinum Casting Theory

What will "freeze" first?

In order to achieve optimal results, it is necessary to fully understand what is happening, as well as the sequence of events as they occur, during the casting process.

Platinum is unique in that, theoretically, it expands very slightly when heated. When it reaches its melting point it liquefies into approximately 20% more volume than in its solid state. Upon solidification the opposite occurs in that the platinum decreases approximately 20% in volume.

In platinum casting practice, inside the mold the liquid metal that is touching the surface of the investment solidifies first. As it shrinks, more liquid metal is supplied by the centerline of the casting, which fills the voids that occur during solidification. As the pattern solidifies, the centerline starts to freeze and draws more liquid metal from the feeds. After the pattern is completely solid, only then can the feeds (gates, risers, sprue, etc.) solidify. Only after all the feeds are solid can the button solidify. If everything occurs in this order the pattern will be very dense with no porosity at or near the surface of the casting. The feeds, however, will be less dense since they solidified after the piece. The button should be full of holes, as it solidified last.

In order for everything to go according to plan, we must be able to predict what will freeze first. Fortunately, there is a formula for calculating this. Let us look at *fig 1-1*, where we have two containers equal in volume. The one on the left *(a)* is 10 x 10 units. The one on the right *(b)* is 7 x 20.4 units. Which one will freeze first? Let us analyze each mathematically.

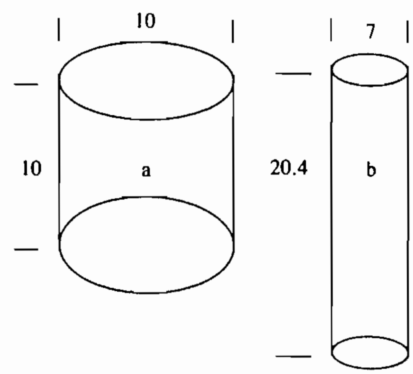

Fig. 1-1: Two containers equal in volume. Which one will freeze before the other?

Chvorinov formula states that:
$(volume / surface\ area)^2 K = t_{sec}$
t_{sec} is the time in seconds it takes to solidify. **K** is a constant which varies with set parameters such as alloy, etc.. The **volume** is equal to the cross sectional area of the cylinder x height.

Since the height = 10 units
and the diameter = 10 units,
the cross sectional area of a cylinder = .7854 x $(\text{diameter})^2$
.7854 x (10 x 10) = 78.54
78.54 x 10 =785.4 units^3
so the volume is **785.4 units^3**

Next, the total **surface area** is equal to the circumference of the cylinder x height, plus the cross sectional area of the cylinder for the top surface, plus the cross sectional area of the cylinder for the bottom surface.

The circumference of a circle is equal to π x diameter

π = 3.1416
3.1416 x 10 = 31.416 units circumference
31.416 x 10 = 314.16 units^2

Next we must add the cross sectional area of the cylinder twice

.7854 x (10 x 10) =	78.54 units^2
	x 2
	157.08 units^2
	+ 314.16 units^2
total surface area =	**471.24 units^2**

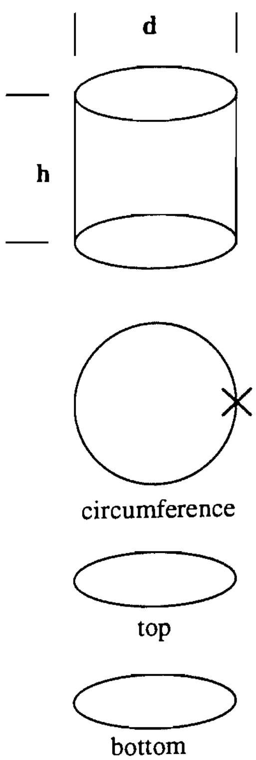

Fig. 1-1a: Components of a Cylinder

Chvorinov formula states that:
(volume / surface area)^2 K = t_{sec}
t_{sec} is the time in seconds it takes to solidify

K is a constant which varies with set parameters such as alloy, etc.
(volume=785.4 units^3 / surface area 471.24 units^2)^2 x K = t_{sec}
(785.4 units^3 /471.24 units^2)^2 =
(1.666)^2 = 2.777

so if our coefficient **K** = **1** our
t_{sec} = **2.777 seconds**

The **volume** is equal to the cross sectional area of the circle x height
Since the height = 7 units
and the diameter = 20.408 units
The area of a circle = .7854 x (diameter)^2
.7854 x (7 x 7) =38.4846
38.4846 x 20.408 =785.4 units^3
so the volume is equal to **785.4 units^3**

Next, the total **surface area** is equal to the circumference of the circle x height, plus the cross sectional area of the circle for the top surface, plus the cross sectional area of the circle for the bottom surface.

The circumference of a circle is equal to π x diameter
π x= 3.1416
3.1416 x 7 = 21.9912 units circumference
21.9912 x 20.408 =448.796 units^2

Next we must add the cross sectional area of the circle twice

.7854 x (7 x 7) =	38.4846 units^2
	x 2
	76.9692 units^2
	+ 448.796

total surface area = **525.7652** units^2

Chvorinov formula states that :
(volume / surface area)^2 K = t_{sec}
t_{sec} is the time in seconds it takes to solidify. **K** is a constant which varies with set parameters such as alloy, etc.
(volume=785.4 units^3 / surface area=525.765units^2)^2 x K = t_{sec}
(785.4 units3 /525.765 units^2)^2 =
(1.4938)^2 = 2.2315
so if our coefficient **K** = **1 our**
t_{sec} = **2.2315 seconds**

In conclusion, *(b) will freeze before (a) will.* This is due to the difference in surface area.

In the next example we will keep the thickness and height the same and we will change the shape. In *fig 1-2*, the left object has a square shape to it and the right object is cylindrical as before.

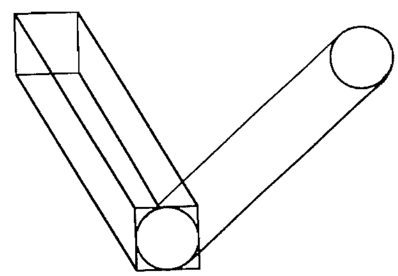

Fig. 1-2: Two objects equal in length and thickness but different shape.

The volume is equal to the cross sectional area of the cylinder x height
Since the height = 10 units and the diameter = 1 unit
The area of a circle = .7854 x (diameter)^2
.7854 x (1 x 1) = .7854
.7854 x 10 = 7.854 units^3
so the volume of the cylinder rod is equal to **7.854 units^3**

Next, the total surface area is equal to the circumference x height + the area of the top and bottom cross sections.
The circumference of a circle = π x diameter
π x= 3.1416
3.1416 x 1= 3.1416 units circumference
3.1416 x 10 = 31.416 units^2

Next we must add the area of the circle twice.

.7854 units
x 2
1.5708 $units^2$
+ 31.416 $units^2$

total surface area = **32.9868 $units^2$**

Chvorinov formula states that:
(volume / surface area)^2 K = t_{sec}
(volume=7.854 $units^3$ / surface area=32.9868 $units^2$)^2 x K = t_{sec}
(7.854 $units^3$ /32.9868 $units^2$)^2 =
(0.2381)^2 = 0.0567
So if our coefficient **K = 1** our **t_{sec} = 0.0567 seconds**
The **volume** is equal to the cross sectional area of the square x height
Since the length of rod = 10 units and the diagonal thickness of square = 1 unit.

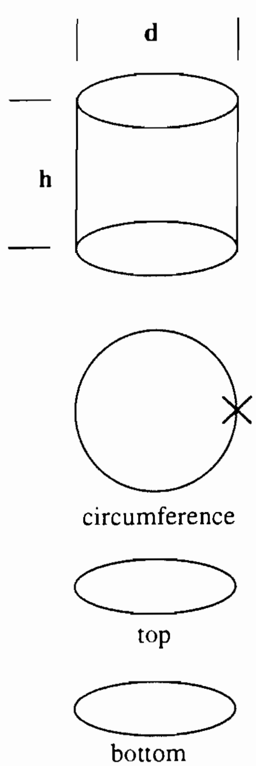

Fig. 1-2a: Components of a Cylinder.

If we divide the square cross section into two triangles we would then have the hypotenuse of the right triangle = 1

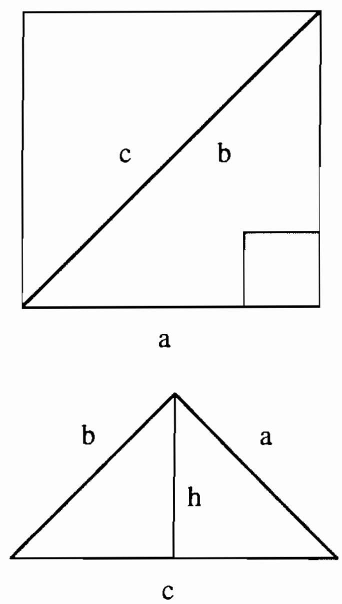

Fig. 1-2b: Square cross-section

The area of the triangle =
½ base (c) x height (h)
c=1
h=(½)c=0.5
0.5 x 0.5 = 0.25 $units^2$ = area of triangle
The area of the square cross section = 2 x (area of triangle)
2 x 0.25=0.5 $units^2$
The volume = area of square x length of rod = 0.5 x 10 = 5
so the volume of the square rod is equal to **5 $units^3$**

Next, the **total surface area** is equal to the perimeter x length plus the area of the top and bottom.

The perimeter of a square is the sum of the four sides.
Since the side is = a
$a^2 = h^2 + (½c)^2 = 0.5^2 + 0.5^2 = 0.5 = a^2$

$\sqrt{.05}$ = .707 = a

a x 4 (sides) = 2.8284 perimeter
2.8284 x 10 (height) = 28.284 $units^2$

The area of the top and bottom is equal to the thickness^2 x 2

0.707 x 0.707 = 0.5 x 2 =1 $units^2$

28.284 + 1 = **29.284 $units^2$**

The surface area of the square rod is equal to 29.284 $units^2$
(5 $units^3$ / 29.284 $units^2$)^2 =
(0.171)^2 = 0.0292
So the time it takes to freeze is **0.0292 seconds**

In the next example let us look at a cylindrical disk that is 1 unit in thickness with a diameter of 10 units verses a cylindrical rod 1 unit in thickness and 10 units long.

First let us look at the disk on the left in *fig. 1-3*. The diameter of the disk is equal to 10 units and the thickness or height of the disk shaped cylinder is equal to 1 unit. The **volume** is equal to the cross sectional area of the cylinder x height.

Since the height = 1 unit
and the diameter = 10 units
The cross sectional area of the cylinder = .7854 x (diameter)^2
.7854 x (10 x 10) = **78.54 $units^2$**
78.54 x 1 = 78.54 $units^3$ and the volume is equal to **78.54 $units^3$**

Next, the total surface area is equal to the circumference of the cylinder x height, plus the cross sectional area of the cylinder for the top surface, plus the cross sectional area of the cylinder for the bottom surface.

The circumference of a circle is equal to π x diameter
π x= 3.1416
3.1416 x 10 = 31.416 units circumference
31.416 x 1 = 31.416 $units^2$

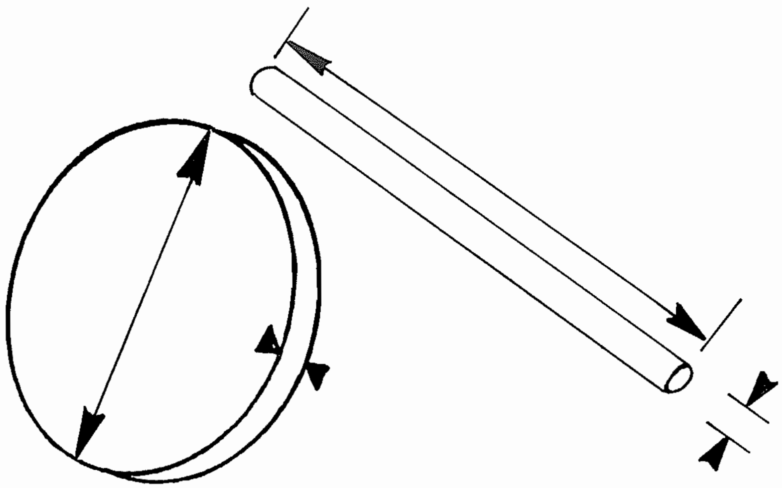

Fig. 1-3: A cylindrical disk 1 unit thick versus a cylindrical rod I unit thick. The diameter of the disk is equal to the length of the rod = 10 units

next we must add the cross sectional area of the circle twice.

.7854 x (10 x 10) = 78.54 units^2
x 2
157.08 units^2
+ 31.416 units^2

total surface area = **188.496 units^2**
(78.54 units^3 / 188.496 units^2)^2 =
(0.42)^2 =0.18

So the time it takes the **disk** to freeze is **0.18 seconds**

Next, let us look at the cylindrical rod on the right in *fig. 1-3.* The thickness or diameter of the rod is equal to 1 unit and the height of the cylindrical rod is equal to 10 units.

The volume is equal to the cross sectional area of the cylinder x height.

Since the height = 10 units
and the diameter = 1 unit
The cross sectional area of the cylinder = .7854 x (diameter)^2
.7854 x (1 x 1) = .7854 units^2
.7854 x 10 =7.854 units^3
So the volume is equal to **7.854 units^3**

Next, the total **surface area** is equal to the circumference of the cylinder x height, plus the cross sectional area of the cylinder for the top surface, plus the cross sectional area of the cylinder for the bottom surface.

The circumference of a circle is equal to π x diameter
π x= 3.1416
3.1416 x 1 = 3.1416 units circumference
3.1416 x 10 = 31.416 units^2
Next we must add the cross sectional area of the circle twice

.7854 x (1 x 1) = .7854 units^2
x 2
1.5708 units^2
+ 31.416 units^2

total surface area = **32.987 units^2**
(7.854 units^3 / 32.987 units^2)^2 =
(0.238)2 =0.0567

So the time it takes the **rod** to freeze is **0.0567 seconds**

The rod will freeze before the disk will!

In this next example we lead up to a simple ring. If we use the same disk from the previous example (a) and subtract from it a smaller disk, (b) what we have left (c) is in effect a simple ring (see *fig. 1-4*)

Since we already know the volume of our cylindrical disk from *fig 1-3* there is no need to calculate it again for disk (a) in *fig 1-4*
volume disk a = 78.54 units^3
We must, however calculate the volume of disk (b) in *fig 1-4*
diameter of disk (b) = 8 units
thickness or height of disk (b) = 1 unit.
The **volume** is equal to the cross sectional area of the cylinder x height.
The cross sectional area of the cylinder = .7854 x (diameter)^2
.7854 x (8 x 8) = 50.2656 units^2
50.2656 x 1 = 50.2656 units^3

so the **volume of disk (b) = 50.2656 units^3**

The **volume of the ring** (c) is equal to disk a minus disk b
78.54-50.27 = **28.27 units^3**

Next, the total surface area of our ring (c) is equal to the circumference of the cylinder (a) x height, plus the circumference of the cylinder (b) x height, plus [the cross sectional area of the cylinder (a) minus the cross sectional area of the cylinder (b)] for the top surface, plus [the cross sectional area of the cylinder (a) minus the cross sectional area of the cylinder (b)] for the bottom surface.

The circumference of a circle is equal to π x diameter
π x= 3.1416
3.1416 x 10 = 31.416 units circumference disk (a)
31.416 x 1 = 31.416 units^2
3.1416 x 8 = 25.1328 units circumference disk (b)
25.1328 x 1 = 25.1328 units^2

Next we must add the [the cross sectional area of the cylinder (a) minus the cross sectional area of the cylinder (b)] for the top surface, plus [the cross sec-

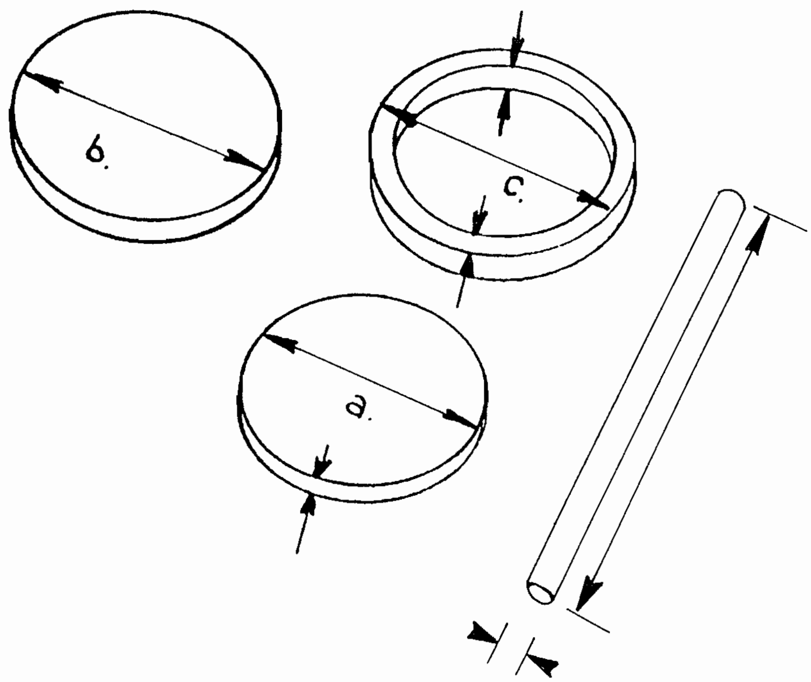

Fig. 1-4: A cylindrical disk same as before, 1 unit thick (a), minus a smaller cylindrical disk (b), also 1 unit thick. Diameter of disk (b) is only 8 units.

tional area of the cylinder (a) minus the cross sectional area of the cylinder (b)] for the bottom surface.

disk (a) = .7854 x (10 x 10) = 78.54 units^2

disk (b) = .7854 x (8 x 8) = 50.2656 units^2

ring (c) = **disk** (a) - **disk** (b)

$$\begin{array}{r} 78.54 \\ \underline{-50.2656} \\ 28.2744 \\ \underline{\times 2} \\ 56.5488 \\ +\ 31.416 \\ \underline{+\ 25.1328} \end{array}$$

surface area = 113.0976

$(28.2744\ \text{units}^3 / 113.0976\ \text{units}^2)^2 = (0.25)^2 = 0.0625$ seconds

The volume of the rod is equal to 7.854 units^3

The total **surface area** is equal to the circumference of the cylinder rod x height. Since we are using the rod as a sprue we wont include the ends in the surface area calculation. One end will join the ring at the gate and the other end connects to the button.

The circumference of a circle is equal to π x diameter

π x= 3.1416

3.1416 x 1 = 3.1416 units circumference

3.1416 x 10 = 31.416 units^2

The surface of the rod is equal to 31.416 units^2

$(7.854\ \text{units}^3 / 31.416\ \text{units}^2)^2 =$ (0.25)2 = 0.0625 seconds

0.0625 = 0.0625

The rod will freeze at the same rate as the ring!

We stated earlier that liquid platinum shrinks approximately 20% in volume upon solidification. We also stated that **the ring must freeze before the sprue.**

When this happens the sprue feeds the centerline of the ring with more liquid metal as the surface of the ring solidifies. In the example ring that we just calculated the ring freezes at the **same interval in time** that the sprue rod freezes. If we allow this to occur we will get irregular shaped voids randomly located throughout the ring. This is commonly called **shrinkage porosity**. We can avoid this problem by making the sprue rod solidify slower.

If we take a look at the cross sectional area of the ring shank we will find that it is square shaped and is 1 x 1 units^2 in area at the cross section. If we double this number (so that the sprue solidifies after the ring due to it now being double the cross sectional area of the ring shank) then divide by .7854 we get 2.5465 we then take the square root to get 1.5958 units in diameter of our new sprue. Why?

Because the area of a circle is = (π x/4) = [3.1416/4] = .7854 multiplied by the diameter squared. So first we find area of thickest cross section of the ring shank: cross sectional area = cross sectional length x cross sectional width.

Then multiply by 2 (or any number between 1.5 and 2.5). The answer is equal to the cross sectional area of the sprue (which is a circle). But we need to know the thickness or diameter of the sprue. So...

area = (π/4) x $(\text{diameter})^2$

divide both sides by (π x/4)

$$\frac{\text{area}}{(\pi/4)} = \frac{(\pi/4)\times(\text{diameter})^2}{(\pi/4)}$$

Now $(\text{diameter})^2$ is equal to area /(π/4)

but we need to know the diameter so...
take the square root of both sides

$$\sqrt{\frac{\text{area}}{(\pi / 4)}} = \sqrt{\frac{(\pi / 4) \times (\text{diameter})^2}{(\pi / 4)}}$$

so $\sqrt{\text{area} / (\pi / 4)} = \text{diameter}^2$

Our new sprue has a 1.59 units diameter. Let us calculate the time it will take for this new sprue to solidify.
The thickness or diameter of the sprue rod is equal to 1.5958 units and the height of the cylindrical sprue rod is equal to 10 units.
The **volume** is equal to the cross sectional area of the cylinder x height.

Since the height = 10 units
and the diameter = 1.5958 units
The cross sectional area of the cylinder = .7854 x $(\text{diameter})^2$
.7854 x (1.5958 x 1.5958) = 2 units^2
2 x 10 =20 units^3
so the volume is equal to 20 units^3
Next, the total surface area is equal to the circumference of the cylinder x height.
The circumference of a circle is equal to π x diameter
π x= 3.1416
3.1416 x 1.5958 = 5.0134 units circumference
5.0134 x 10 = 50.134 units^2
total surface area = **50.134 units^2**
$(20 \text{ units}^3 / 50.134 \text{ units}^2)^2 =$
$(0.3989)^2 = 0.159$
So the time it takes the **sprue rod** to freeze is 0.159 **seconds**

Our new sprue rod freezing interval takes **2.5 times longer** than it takes the ring shank to solidify. This will ensure proper feeding to the centerline of the ring shank and increase the density of the casting.

Note that the relationship in time is **more than double** that of the ring. All feeds must solidify at this interval relationship. This includes risers and auxiliary sprues.

Note also that too large an interval is also not beneficial to feeding the ring shank. If the sprue is too big it will slow down the cooling rate of the shank and cause shrinkage porosity at the gate area under the sprue. This is visible after removal of the sprue and filing of the shank.

Casting Problems Defined

The casting problem, as any other, may be divided into general parts:

Design Problems

The Design and Production of the Mold or Flask

(A) The Mechanism and Rate of Metal Solidification.

For the sprue gates and risers to be placed and proportioned properly, the crystallization pattern and shrinkage in volume accompanying solidification must be known. These factors vary considerably, depending upon the chemical composition of the metal and the thermal gradients in the mold. If you want to make plate or rod, for example, you would use a cold mold, which is water cooled. If you want to cast rings, you would use a heated flask that was burnt out properly. Platinum shrinks approximately 20% in volume upon solidification.

(B) Heat Transfer During Solidification (Risering).

After the solidification process is understood one can proceed to study the control of shrinkage porosity by application of heat-transfer principles. If the volume of the liquid metal is greater than that of the solid metal, voids will occur unless steps are taken to change the natural thermal gradients. We need to know what can be done to change the heat-transfer conditions. The use of liquid-metal reservoirs (risers) and chillers can be beneficial to the solidification process so that the pieces solidify before the risers and sprue gates.

(C) The Flow of Liquid Metal.

The problems involved here are illustrated by the following questions: What are the calculations leading to the selection of proper pouring temperature? On one hand we must avoid overheating the metal to the point where porosity becomes an issue, and on the other, we must prevent solidification of the metal stream before the mold is completely filled. How will the channels for delivering the metal (the gating system) be designed?

Sprue Gate Design

The objective of a sprue-gating system is to permit distribution of the metal to the mold cavity at the proper rate, without excessive temperature loss, free from objectionable turbulence and entrapped gases.

Any good gating system is the result of considered engineering compromises. Metal and mold compositions affect the choice of design for a gating system. The characteristics of a heated ceramic mold such as is used in investment (or "lost wax") casting permit variations in the gating system customarily used with cold molds of other compositions.

The gate should enter the heaviest section of the ring. It should be a single, heavy sprue one and one half times the size of the cross-sectional area it is feeding. It should have fillets at the joint flaring the gate slightly (no 90° corners). This will slightly increase the surface area at the junction and will minimize any turbulence when the metal enters the piece. When there is turbulence there is pickup of gases present during the casting process. These gases can later surface in the pieces.

Riser Design

Risering is, of course, a process designed to prevent the formation of shrinkage voids in the casting upon solidification. The point to recognize is that contraction can take place at a constant temperature or over a narrow range and is the result of a density change accompanying the transformation from liquid to solid. Shrinkage porosity can be solved by controlling the solidification pattern and thermal gradients so that the voids are produced outside the body of the casting proper. To produce a sound casting, the riser or reservoir of liquid metal which is to compensate for the shrinkage must satisfy two independent requirements.

(A) Riser Size.

If the riser is to supply liquid metal to feed the casting shrinkage, it must freeze after the casting. The ratio (volume/surface area^2) of the riser must exceed that of the casting.

(B) Riser Placement.

For an alloy with high centerline feeding resistance, a casting will require a closer spacing of risers than for other alloys. In other words, the effective feeding distance of a riser in a wide-freezing band alloy is smaller than in a narrow-band alloy.

Centerline Feeding Resistance

We can define a term to quantify the ease of feed to a casting. We know that once the centerline has solid crystals difficulty occurs. We also know that the greater the percentage of total solidification time during which these centerline crystals are present in a casting, the more difficulty there is in feeding. So our centerline feeding resistance can be equated to:

$$\text{CFR} = \frac{\text{time during which crystals are forming at centerline}}{\text{total solidification time of the casting}} \times 100$$

Steps of the design and production of the mold (flask);

1. Design of piece to be replicated
2. Model-making, correct location and size of gate and risers
3. Wax injection mold (rubber mold)
4. Injection of the wax
5. Investing
6. De-waxing

Process Problems

Effect of Mold Temperature.

In lost-wax casting, the temperature of the mold or flask varies greatly. This is due primarily to the nature of the casting method. For example, shell casting is done with room-temperature molds, which are high pressure, steam de-waxed in an autoclave. Investment mold vacuum (or static casting) flask (or mold) temperatures are usually 150-250° F higher than if centrifugal cast. This is necessary so that all the pieces totally fill in the absence of centrifugal force. A secondary reason for temperature variation is what you are trying to cast, for example, a filigree piece (hotter) or a thick-shank, solid-wall men's ring (cooler). The higher the temperature (inside the mold or flask), the longer a mushy condition, i.e., liquid + solid, exists. The lower the temperature, the more rapid the freezing occurs. This is due to the dissipation of the heat away from the molten metal into the flask and ultimately into the atmosphere. The casting must freeze at the surface first, then gradually solidify inward. The centerline must freeze last.

Melting, Refining and Transfer of Liquid Metal

(A) Gases in Metals

During melting, porosity in castings is often produced by solution of gases in liquid metal which are less soluble in the solid metal and therefore precipitate as bubbles, leading to holes and porosity. The gates can contribute to this by introducing turbulence and entrapping gases during the casting process. The open-air system of melting the metal can also contribute to gases being absorbed into the metal. Another source of gas is from the flame of the torch or furnace. If not adjusted correctly, the flame can adversely affect the metal by absorption of excess gases, especially reducing gases such as CO, H_2 and CH_4. The reducing gases will change the characteristics of the metal and cause embrittlement and cracking. Reducing gases or getter gases can also create havoc on silica (SiO_2) by changing its form to silicon (Si), which can be also absorbed by the metal in the charge. Since most refractory materials used in platinum casting are made of silica, there lies a potential for contamination if mishandled during use.

Platinum can be refined to some extent by melting the metal and allowing it to begin to solidify, causing a snow cap, and then remelting the metal again. By doing this several times you can de-gas the charge and also remove contaminants by allowing them to gradually float to the top where they solidify with the snow cap. Later, as the charge remelts, the cap rolls over to one side and the contaminants are removed by sticking to the crucible. Induction heating is ideal for this process because the charge is heated from the bottom upwards to the cap of the charge, unlike a torch, which is heated from the flame downwards. Medium frequency induction has an additional benefit of mixing the metal automatically by means of magnetically stirring the charge with the edy currents that have penetrated deep into the charge. This phenomena can be visually observed and measured by turning the medium frequency induction on and off and measuring the amount the reverse meniscus rises and falls. Under ideal circumstances the frequency and kilowatt power of the induction generator causes the metal to stand the maximum distance upward when medium frequency induction is applied.

(B) Control of Common Elements

When service tests have shown a metal of a certain composition and color to be most desirable, we need to determine what combination of scrap, furnace conditions, temperature/soak time and casting machine is necessary for reliable, economical production.

The best way to get repeatable and consistent results is to use the same amount of metal in every melt and apply heat to the point where the metal is 100% liquid. At this point, remove the heat and allow the charge to cool to the point where the metal is starting to freeze. Next, reheat the metal to its liquidus point and continue to heat for a fixed interval in time (soak time) until transfer of metal occurs. This method ensures homogeneity of temperature as well as alloy mixture at the point in time when transfer occurs.

Metal should transfer quickly and smoothly so that differences in metal temperature do not occur due to cool off during transfer. The metal that leaves the crucible first should not be hotter than the metal that leaves last. If this happens, the metal that reaches your rings will be hotter than the metal inside your sprues and solidification will not occur in the correct sequence. It is extremely important that the metal in the charge be the same temperature throughout. If it is not the same temperature, the hotter metal will flow out before the cooler metal. Remember also to ensure that the crucible hole is sufficiently large to transfer the charge without any cool-down inside the crucible.

If you are using a torch, you must mix the metal with the flame of the torch carefully to ensure none of the metal leaves the crucible's dish. With the proper skill, this technique can produce acceptable results. This technique, however, requires considerable experience in order to perfect.

The transfer of the metal to the mold can be accomplished several different ways and the method chosen depends upon what you are trying to make. For example, plate and rod is made differently than casting rings. Platinum group metals by themselves do not require any inert gases or vacuum during the melting process, due to their noble properties. They can be reused over and over, providing no impurities or gases have been introduced during the casting process. Non-platinum group metals, however, do require some sort of control of the atmosphere in order to retard oxidation and ensure reusability. Cobalt-platinum alloys react best to medium frequency induction melts under vacuum. Argon backfill or cover gas can be used as an alternate method.

The different methods include:

Casting method
- centrifugal
- centrifugal with vacuum
- static pour
- vacuum assist static
- vacuum and pressure assist
- pressure assist static

Melting method
- open air
- closed system
- hydrogen torch
- induction
  - high frequency
  - medium frequency.

Material Problems

Rate of Solidification of Different Alloys

The solidification of alloys differs in three principal ways from that of pure metals:

1. Usually, the freezing of alloys occurs over a temperature range
2. The composition of the solid which separates first is different from that of the liquid
3. There may be more than one solid phase crystallizing from the liquid.

Effect of Alloy Composition

It is an experimental fact that some alloys are far easier to feed than others, given the same flask temperature. In general, those with the smallest liquidus-to-solidus interval are easiest to feed, while those with a long freezing range present difficulties. In general casting experience, it has been found to be difficult to satisfactorily feed alloys which have a centerline feeding resistance of more than 70%. The 88/10/2 bronze (CFR95) behaves quite differently from the 60/40 brass (CFR26), although both are copper-based materials. Platinum offers many different alloy compositions, some of which include:

95% Purity

Cobalt Platinum
5%Co 95%Pt
Cobalt - Copper Platinum
3%Co 2%Cu 95%Pt
Cobalt -Palladium Platinum
3%Co 2%Pd 95%Pt
Copper Platinum
5%Cu 95%Pt
Palladium Platinum
5%Pd 95%Pt
Iridium Platinum
5%Ir 95%Pt
Ruthenium Platinum
5%Ru 95%Pt

90% Purity

Iridium Platinum
10%Ir 90%Pt
Palladium Platinum
10%Pd 90%Pt
Palladium Cobalt Platinum
7%Pd 3%Co 90%Pt

Causes of Porosity (Holes)

There are four major causes of porosity:

1. Overheating of the metal [process problem, metal problem].
2. Carbon residue after burnout [process problem, metal problem]. Foreign residue contamination present on old scrap metal 50%-50%.
3. Improper gate location, dimensions, shape [design problem].
4. Too high a flask temperature [process problem].