

# 1. Introduction

In this study we have looked for an alloy with colour similar to the reference alloy, but with the best combination of characteristics for investment casting.

The most important characteristics for investment casting are:

- 1. Mould filling ability
- **2.** Gas and shrinkage porosity
- 3. Grain size
- 4. Resistance to oxidation during casting
- **5.** Melting temperature of the alloy
- 6. Melting range
- 7. Hardness

These characteristics have a different degree of importance, when we make different practical and metallurgical considerations. Obviously the final result will come out of a compromise among the different requirements.

#### 1. Gas and shrinkage porosity

Gas porosity should be completely absent.

Shrinkage porosity cannot be eliminated, but it should be suitably distributed and located. This means that the voids produced by the contraction of the metal during solidification should be situated to the feed sprue and/or inside the bulk and away from the surface of the casting.

#### 2. Resistance to oxidation

Resistance to oxidation is obtained mainly with the addition of silicon, and is particularly important for casting with stones in place. In this case the cast pieces should be well deoxidised, particularly in the recessed areas under the stones.

#### 3. Grain size

The grain size should be as small as possible, subordinately to the requirements of points 1 and 2 above. Fine grain enables to obtain a shiny polished surface.

#### 4. Melting temperature of the alloy

It should be as low as possible (in all cases lower than 1000°C), to minimize calcium sulphate decomposition, compatibly with points 6 (mould filling) and 1 (porosity).

#### 5. Melting range of the alloy

It should be as narrow as possible, to minimize shrinkage porosity, but a compromise with point 2 should be reached (silicon widens the melting range).

#### 6. Mould filling ability

When other conditions are kept constant, mould filling is strongly influenced by mould and liquid metal temperature. A compromise with points 1, 2 and 4 should be found.

#### 7. Hardness

Usually hardness is not a problem in 14 ct red gold, because sufficiently high hardness levels can be obtained (> 120 HV).

# 2. Experimental

35 different 14 ct gold alloys have been produced with the use of 11 different metal components: Au, Ag, Cu, Zn, In, Ga, Ni, Sn, Re, Ir, Si. Only gold content has been kept constant at 585 ‰. The concentration of the other alloying elements has been varied in the following ranges:

Ag	40	al	80‰
Zn	0	al	25‰
In	0	al	10‰
Ga	0	al	10‰
Ni	0	al	8‰
Sn	0	al	3‰
Re	0	al	2‰
lr	0	al	1,25‰
Si	0	al	2,1‰
Cu	balance		

All alloys have been produced with pure, certified metals. A preliminary melting operation has been carried out in an induction heated static furnace. The melt has been protected with a reducing flame of propane gas. The molten metal has been cast in a hot (about 300°C) metal mould, and a 8 mm thick ingot has been obtained. The ingot has then been rolled to 1 mm final thickness and the rolled sheet has been cut into small pieces, suitable for melting in the vacuum casting machine.

A further melting operation has been carried out for the specimens used for the visual observation of the sides of the rolled sheet. The molten metal has been cast in the same mould as before and has then been submitted to a 60-75% rolling reduction.

The following experimental conditions have been used for all investment cast specimens:

- Metal temperature: 100°C above liquidus temperature
- Flask temperature : 550°C
- Overpressure after casting: 2.5 bar
- Delay before water quenching: 10 minutes
- Weight of the melt: 185 grams

The tree used for investment casting tests was composed of 3 spheres with 15.5 mm diameter, with a 3.9 mm diameter feed sprue. The spheres where put side by side with feeding from the top. Also four 16 x 8 mm, 2mm thick small plates are present in the tree.

The spheres have been numbered 1, 2 and 3 and have been cut perpendicularly to the feed sprue, to obtain 2 hemispheres, that have been used for studying shrinkage porosity and crystal structure. The small plates have been used for colour evaluation.

The shape of the tree and the size and position of the spheres and related feed sprues have been chosen for making defects more evident and represent our factory standard for comparative tests.

Later a set of tables with the composition of the experimented alloys will be shown, with a corresponding set of plates, showing:

- The cast tree.
- The crystal microstructure of the casting.
- The defects present in the spheres in the positions 1, 2 and 3
- The aspect of the surface and/or of the sides of the rolled specimens

The general plan of our work started from the production and evaluation of a first set of alloys, containing the various alloying elements, to make a first set of comparative tests, to reach preliminary conclusions. Subsequently a second set of alloys has been more specifically designed to obtain the final result.

### 3. Preliminary tests

#### Effect of zinc, indium and gallium

Table 1 shows the composition of the reference alloy (1\_RIF585\_80AgCu), that is the starting point for designing the set of experimented alloys.

Table 1 – Composition of the alloys, wt ‰

Alloy	Au	Ag	Zn	Cu	Ga	In
1_RIF585_80AgCu	585	80	-	335,0	-	-
2_AgZnCu	585	70	8	337,0	-	-
3_AgInCu	585	70	-	337,0	-	8
4_AgGaCu	585	70	-	337,0	8	-

From Plate 1 we can see that:

• The tree is oxidized in all cases (a little less for alloy 4).

• In the reference alloy, shrinkage defects are mainly situated in the inner part of the castings, but in the other alloys they are nearer to the surface.

• Surface defects are more or less evidently present in all alloys.

• Grain size is drastically reduced by the addition of zinc, and is even more drastically reduced by indium and gallium additions.

The most important effect observed with these alloys is that Zn, In and Ga, separately added to the reference alloy, cause appreciable grain refinement in the cast pieces. The best result has been given by gallium.

# 4. Effect of silicon

The composition of a set of silicon containing alloys is shown in Table 2.

#### Table 2 – Composition of the alloys, wt‰

Alloy	Au	Ag	Zn	Cu	Ga	In	Si
5_AgZnCuSi100	585	70	8	336,9	-	-	0,100
6_AgZnCuSi200	585	70	8	336,8	-	-	0,200
7_AgZnCuSi300	585	70	8	336,7	-	-	0,300
8_AgZnCuSi400	585	70	8	336,6	-	-	0,400
9_AgZnCuInSi600	585	75	8	323,4	-	8	0,600
10_AgZnCuGaSi600	585	75	8	323,4	8	-	0,600
11_AgZnCuSi2100	585	65	14	333,9	-	-	2,100

Alloys 5 to 8 have similar composition, the only difference being the addition of steadily increasing amounts of silicon (100 to 400 ppm), to evaluate the deoxidisation effect.

Alloys 9 and 10 have been used to study the combined effect of silicon (600 ppm) and indium and gallium with constant zinc content.

Alloy 11 contains a large amount of silicon (2100 ppm) with an increased content of zinc and lower

silver content.

From Plate 2 (alloys 5 to 8) we can see that:

- Going from alloy 5 to alloy 8 the deoxidisation of the cast tree is gradually improving, but oxide residues are always present (incomplete deoxidisation)
- Shrinkage defects are situated in the inner part of the castings
- · Surface defects are minimal in all alloys
- Grain size is large and similar to the reference alloy

The most important effect observed in this set of alloys is that shrinkage defects are situated in the inner part of the castings and surface defects are reduced, but grain size is very large.

From Plate 3 (alloys 9-10-11) we can see that:

- In all cases the tree is fully deoxidised (the best performance has been given by alloy 11 which contains more silicon)
- Shrinkage defects are situated in the inner part of the castings, with the exception of alloy 11 (higher silicon content), where they are nearer to the surface
- Surface defects are minimal in alloys 9 and 10, but are evident in alloy 11
- All alloys show large grain size. In alloy 11 a lamellar structure has been observed that is directed towards the inner part of the castings

The most important effect observed in this set of alloys is that, up to a silicon content of 600 ppm, shrinkage defects are situated in the inner part of the castings and surface defects are reduced, but grain size is very large.

# Considerations on the behaviour of silicon in alloys for investment casting

It is well known that silicon improves form filling and deoxidisation of the castings.

Up to now it has been believed that silicon alone and its reaction with oxygen (oxygen could come from air or be already present in the alloy), with formation of silica (SiO2), could explain the good deoxidisation of the cast tree and the improved filling of the mould.

The preliminary results of the studies carried out by ProGold suggest that this could be only partially true. Work is in progress to clarify the real mechanism of silicon effect in investment casting of gold and silver alloys. The results will be shown in a forthcoming Conference on jewellery manufacture technology.

At present we can say that silicon forms some kind of compound with high surface tension in the molten alloy. This compound goes to the surface of the melt and forms a thin layer, which hinders the evaporation of zinc and all volatile (low boiling point) components of the alloy.

In the case of investment casting, this film minimizes the direct contact of the metals forming the alloy with calcium sulphate and the related reactions, even if a reaction of this film with calcium sulphate or with calcium sulphate decomposition products cannot be excluded.

Therefore it has been hypothesized that this film, that is free from oxides and sulphides, in addition to reduce the reaction of the alloy with the decomposition products of calcium sulphate, can let the liquid metal flow more easily on the investment, improving mould filling. Also the interfacial tension between the "silicon compound" and the investment should be taken into account.

The above stated hypothesis has been confirmed by the following experiments:

- The main sprue of a tree produced with a silicon containing alloy has been heated to 650°C in a furnace with oxidizing atmosphere and it has been observed that only the cut surfaces of the gates oxidized. The remaining surface of the sprue remains unaltered. It has been deduced that the silicon compound is present only on the outer surface of the sprue. This compound could form in the liquid phase and during solidification. Also a reaction with calcium sulphate could take place, or a combination of different factors. The study started from this observation.
- 2) During the tests performed with Differential Thermal Analysis (DTA), to determine melting and solidification temperature of zinc containing alloys with or without silicon (other components being the same) a weight loss has been observed only in the specimens without silicon.

Further experiments have been carried out with a 14 ct gold alloy containing 6.3% zinc and no silicon. The composition of the alloy has been determined before and after the DTA test and it has been found that more than 90% of the zinc had been lost. The zinc loss corresponded to the weight loss of the specimen, and this means that nearly all the zinc has evaporated.

Moreover the examination of the DTA graphs already showed an anomaly between the heating and the cooling curves. The solidus and liquidus temperatures (start and end of melting) measured during heating did not match the corresponding temperatures (start and end of solidification) measured during cooling. In particular it has been observed that the solidification started at a temperature higher than the temperature of complete melting, as if two different alloys were present.

On the contrary, with the alloy containing both

zinc and silicon, the weight loss has been very limited (less than 10% of the zinc content). (The 14 ct gold alloy contained 300 ppm silicon and 6.3% zinc). For this alloy the DTA tests showed a very good match between the heating and the cooling curves.

Further tests confirmed the above describe results.

#### Effect of the grain refiner

The composition of the alloys used for a preliminary study of the effect of the grain refiners is shown in Table 3.

Table 3 - Composition of the alloys, wt‰

Alloy	Au	Ag	Zn	Cu	lr
1_RIF585_80AgCu	585	80	-	335,0	-
34_Ir1245AgZnCu	585	74,7	4,1	334,9	1,245
35_Ir1200AgZnCu	585	45	25	343,8	1,200

These alloys are designed for plastic deformation. We will not dwell on mechanical characteristics, but we will only consider the effect of the grain refiner. In this case iridium has been used.

Alloy 1 is the reference alloy, while alloys 34 and 35 contain different zinc additions. Silver content has been reduced to keep the desired colour (see Table 7, later).

The appearance of the surface and of the sides of the rolled specimens (75% cold reduction) has been compared with grain size (obtained after annealing at 650-700 or 750°C for 18 minutes), to show as this empirical but practical method could be used for a preliminary evaluation of the grain size of an alloy.

From Plate 4 we can see that:

- Alloy 35 shows the side surface with lower roughness, i.e. the finest grain size.
- Alloys 34 and 35, containing a grain refiner, show less grain growth with increasing annealing temperature.
- With the same annealing temperature, grain size is much smaller in alloys with a grain refiner.

We will not dwell on details (mechanical characteristics etc.), but we emphasize that grain refined wrought alloys can be submitted to strong cold deformation and can tolerate higher heat treatment temperatures (annealing, homogenisation and, in the case of chain, soldering) without or with a minimal formation of orange peel.

#### Grain refining of alloys for investment casting

The effect of grain refiners in gold alloys for investment casting is well known. It is evident that an alloy with fine or very fine grain will facilitate the production of thin castings with a highly polished surface.

The use of grain refiners is required also to counterbalance the grain growth caused by silicon addition.

In addition to iridium, whose effect is already well known, preliminary tests have been performed to study the effect of rhenium (Re).

#### Use of rhenium as a grain refiner for investment casting

The composition of different rhenium containing alloys, that are similar to the reference alloy, is shown in table 4.

Alloy	Au	Ag	Zn	Cu	Ga	In	Ni	Sn	Si	Re
12_7Re300AgZnCuIn	585	75	8	319,7	-	8	3,0	1,0	-	0,300
13_7Re700AgZnCuInSi200	585	75	8	313,4	-	8	7,0	2,3	0,200	0,700
14_7Re700AgZnInCuSi600	585	75	8	313,8	-	8	7,0	2,3	0,600	0,700
15_7Re700AgZnCuSi400	585	75	15	309,6	5	-	7,0	2,3	0,400	0,700
16_7Re700AgZnCuSi600	585	75	15	309,4	5	-	7,0	2,3	0,600	0,700
17_15Re750AgZnCuln	585	75	8	319,0	-	8	3,0	1,25	-	0,750
18_15Re1000AgZnCuInSi150	585	75	8	317,2	-	8	4,0	1,67	0,150	1,000
19_15Re750AgCuSi150	585	75	-	326,8	-	8	3,0	1,25	0,150	0,750
20_15Re500AgZnCuInSi150	585	60	20	323,5	-	8	2,0	0,8	0,150	0,500
21_15Re750AgZnCuInSi150	585	60	20	321,8	-	8	3,0	1,25	0,150	0,750
22_15Re1000AgZnCuInSi150	585	60	20	320,2	-	8	4,0	1,67	0,150	1,000
23_15Re2000AgZnCuInSi150	585	60	20	313,5	-	8	8,0	3,33	0,150	2,000

Table 4 - Composition of the alloys, wt‰

The greatest difficulty for the use of rhenium as a grain refiner is given by its insolubility in the metals most commonly used for jewellery production (Ag, Cu, Zn). Therefore a master alloy with these metals cannot be prepared, to guarantee a homogeneous distribution of Re in the molten metal. Rhenium shows 0.1% solubility in liquid gold: this is an interesting aspect deserving further study.

An examination of binary phase diagrams showed that Re has more than 20% solid state solubility in nickel. So nickel can be used to make a master alloy with rhenium. Tin can be used to lower the melting point of the master alloy.

Two master alloys have been prepared, containing 7% and 15% Re respectively, with suitable content of nickel and tin (these alloys have been named 7Re and 15Re respectively).

On the basis of the above considerations, 12 different 14 ct gold alloys have been prepared, with different Re content, to get as complete as possible information on the performances of this grain refiner. The inspection of the sides of the rolled specimens has also been used for the evaluation of grain size, to reduce the time required for the tests. From Plate 5 (alloys 13 - 14 - 15 - 16) we can see that:

- The trees of alloys 14 and 16 are completely deoxidised (Si content = 600 ppm)
- Shrinkage defects are always in the inner part of the casting (Si content from 200 to 600 ppm)
- Grain size is small in alloy 14 (this is an anomalous case, requiring further investigation), and large, similar to the reference alloy, in all other cases

The most important result from this set of alloys is that shrinkage defects are in the inner part of the castings and few surface defects are visible. However grain size is very large.

Grain size is clearly related to the roughness of the sides of the rolled specimens.

From Plate 6 (alloys 12 - 17 - 18 - 19 - 20 - 21 - 22 - 23) (the data on grain size and alloy structure should be compared also with the alloys 13-14-15 and 16 of Plate 5) we can see that:

- Alloy 12 (silicon free) shows very low roughness of the sides of the rolled specimens. This means that Re can be effectively used to refine grain in wrought gold alloys.
- Addition of 600 ppm Si to alloy 12 caused a remarkable increase of roughness of the sides of the rolled specimens.
- The strong increase of grain size caused by Si additions can be seen comparing alloy 17 (no silicon) with alloy 18 (150 ppm silicon).
- Larger amounts of rhenium in the alloy correspond to improved grain refinement (alloys 21, 22 and 23).

From these experiments it can be concluded that the grain refining effect of rhenium in cast alloys is very similar to iridium. However up to now some difficulty has been found for introducing rhenium consistently in the alloys for industrial jewellery production.

In addition to rhenium, we are exploring also the possibility to use ruthenium as a grain refiner in investment casting. Some preliminary tests gave interesting results, so a deeper investigation is presently under way.

# 5. Final tests

On the basis of the above described preliminary tests and of the data shown in Table 7 "CIELab colour coordinates" and in Table 8 "Melting temperature and range", it has been decided to test a second set of alloys with various contents of silicon, zinc, silver and gallium. Indium has been excluded, because it lowers solidus temperature considerably, widens the melting range and forms oxides, like In2O and In2O3, that are volatile at the casting temperature. Iridium has been used for grain refining. The composition of these alloys is shown in Table 5.

Table 5 – Composition of the alloys, wt‰

Alloy	Au	Ag	Zn	Cu	Ga	Ni	Sn	Si	lr	Re
24_Ir700AgZnCuSi400	585	75	15	323,9	-	-	-	0,400	0,700	-
25_Ir700AgZnCuGaSi200	585	75	15	319,1	5	-	-	0,200	0,700	-
26_Ir700AgZnCuGaSi600	585	75	15	319,1	5	-	-	0,600	0,700	-
27_ Ir400Re600AgZnCuGaSi200	585	75	15	310,8	5	0,6	2,00	0,200	0,400	0,600

In this set of alloys the content of Au, Ag and Zn has been kept constant. The effect of different additions of gallium and silicon has been studied. Iridium and rhenium have been used for grain refining (combined effect).

From Plate 7 we can see that:

- The tree is deoxidised in all cases (a little less with alloys 25 and 27, containing only 200 ppm Si).
- Shrinkage defects are noticeable and are directed towards the surface of the castings (with the exception of alloy 27).
- The combined use of Ir and Re (alloy 27) does not improve the grain refining effect.
- Grain size is small only in alloy 25 (200 ppm Si).
- A higher roughness of the side of the rolled specimens (alloy 26) corresponds to a larger grain size.

Table 6 shows the composition of a set of alloys with constant iridium (700 ppm) and gallium (10‰) concentration and different concentrations of silicon (400 to 800 ppm), silver, zinc and copper.

#### Table 6 – Composition of the alloys, wt‰

Alloy	Au	Ag	Zn	Cu	Ga	Si	lr
28_Ir700AgZnCuGaSi400	585	65	15	323,9	10	0,400	0,700
29_Ir700AgZnCuGaSi600	585	65	15	323,7	10	0,600	0,700
30_Ir700AgZnCuGaSi600	585	50	20	333,7	10	0,600	0,700
31_Ir700AgZnCuGaSi800	585	50	20	333,5	10	0,800	0,700
32_Ir700AgZnCuGaSi600	585	50	15	338,7	10	0,600	0,700
33_Ir700AgZnCuGaSi800	585	50	15	338,5	10	0,800	0,700

These alloys represent a conclusive set for achieving the final result.

From Plates 8 and 9 we can see that:

- The tree is satisfactorily deoxidised in all cases.
- Shrinkage defects are always concentrated in the inner part of the castings, with the exception of alloy 31 (800 ppm Si and 20‰ Zn the highest concentration for both additions).

• The roughness of the sides of the rolled specimens corresponds to the grain size.

# 6. Colour evaluation

Some of the experimented alloys have been submitted to colour evaluation, to assess the effect of composition on colour. The results are shown in Table 7.

Alloy	Au	Ag	Zn	Cu	Ga	In	L*	a*	b*
1_RIF585_80AgCu	585	80	-	335,0	-	-	85,6	7,5	17,8
2_AgZnCu	585	70	8	337,0	-	-	85,8	6,9	17,8
3_AgInCu	585	70	-	337,0	-	8	85,5	7,2	17,6
4_AgGaCu	585	70	-	337,0	8	-	85,6	6,8	17,7
5_AgZnCuSi100	585	70	8	336,9	-	-	85,8	7,0	17,4
8_AgZnCuSi400	585	70	8	336,6	-	-	85,8	6,9	17,9
9_AgZnCuInSi600	585	75	8	323,4	-	8	84,9	5,9	18,7
10_AgZnCuGaSi600	585	75	8	323,4	8	-	85,3	5,8	18,1
11_AgZnCuSi2100	585	65	14	333,9	-	-	86,0	5,7	17,9
28_Ir700AgZnCuGaSi400	585	65	15	333,9	10	-	85,8	5,0	19,1
29_Ir700AgZnCuGaSi600	585	65	15	323,7	10	-	85,9	4,9	19,0
30_Ir700AgZnCuGaSi600	585	50	20	333,7	10	-	85,3	5,5	18,9
31_Ir700AgZnCuGaSi800	585	50	20	333,5	10	-	85,0	5,6	18,2
32_Ir700AgZnCuGaSi600	585	50	15	338,7	10	-	85,0	5,8	18,6
33_Ir700AgZnCuGaSi800	585	50	15	338,5	10	-	85,0	5,9	17,9
34_Ir1245AgZnCu	585	74,7	4,1	334,9	-	-	85,1	7,3	18,2
35_Ir1200AgZnCu	585	45	25	343,8	-		86,4	6,0	17,8

Table 7 – CIELab colour coordinates

# 7. Observation

CIELab colour coordinates represent all colours the human eye can see. It is a mathematical system using 3 variables: L\*, a\* and b\*. L\* represents brightness (L\* = 0 corresponds to black, L\* = 100 corresponds to white). a\* represents the colour component going from red to green (a\* = 100 corresponds to fully red, a\* = -100 corresponds to fully green). b\* represents the colour component going from yellow to blue (b\* = 100 corresponds to yellow, b\* = -100 corresponds to blue).

In alloys 2, 3 and 4 Au, Ag and Cu content has been kept constant and the effect of Zn, In and Ga additions is compared. Gallium causes the more important shift towards yellow. If we compare these figures to the reference alloy (alloy 1), we can obtain the following figures, related to silver concentration:

1 - Zn/Ag = 0.402 - In/Ag = 0.50

3 - Ga/Ag = 0.38

This means that 0.40 g of Zn, 0.5 g of In and 0.38 g of Ga cause the same colour shift towards yellow than 1 g of Ag.

These experimental coefficients can be used in

the practice to calculate the colour as a function of composition with an acceptable error for the alloys we are studying.

Silicon causes a trend towards yellow, but does not cause a substantial change of colour, as can be seen from alloys 2, 5 and 8. The effect observed in the alloy 11 is to be ascribed mainly to the higher zinc and lower silver content. The addition of similar amounts of In and Ga with constant Zn and Ag content (alloys 9 and 10) causes a remarkable shift towards yellow in comparison with the similar alloys 2, 3 and 4. Si causes little effect.

The effect of Si has been evaluated in the following pairs of alloys: 28-29, 30-31 and 31-32, where Si is present with various concentrations (400 -600 - 800 ppm). No significant effect has been observed. The observed colour differences are ascribed to the different Ag and Zn content.

Alloys 34 and 35 are used for plastic deformation (no silicon is added).

From a practical point of view, the alloys are considered of a comparable colour, when the difference of a\* is lower than 2.

# 8. Melting temperature and melting range

Several of the experimented alloys have been tested with DTA, to determine melting and solidification temperature, to get further data for evaluation.

The results are shown in Table 8.

Alloy	Au	Ag	Zn	Cu	Ga	In	Solidus [°C]	Liquidus [°C]	∆T [°C]
1_RIF585_80AgCu	585	80	-	335,0	-	-	863	901	38
2_AgZnCu	585	70	8	337,0	-	-	868	903	35
3_AgInCu	585	70	-	337,0	-	8	839	900	61
4_AgGaCu	585	70	-	337,0	8	-	855	894	39
11_AgZnCuSi2100	585	65	14	333,9	-	-	818	892	74
32_Ir700AgZnCuGaSi600	585	50	15	338,7	10	-	848	898	50
34_Ir1245AgZnCu	585	74,7	4,1	334,9	-	-	866	903	37
35_Ir1200AgZnCu	585	45	25	343,8	-	-	873	911	38

Table 8 – Melting temperature and melting range

#### Alloys without silicon

Alloys 2, 3 and 4 have the same content of Au, Ag and Cu and similar additions of Zn, In and Ga respectively. Liquidus temperature shows slight changes, and Ga causes the more appreciable lowering.

Indium causes the most important lowering of solidus temperature, followed by gallium. Indium and gallium are used in solders also for this reason.

Alloy 3, with 8‰ indium shows the wider melting range (61°C).

Alloy 34 is partially comparable with alloy 2 and shows the same temperature figures. Alloy 35, having higher Zn and Cu concentration, shows higher solidus and liquidus temperatures, but the melting range  $(37 - 38^{\circ}C)$  is the same.

#### Silicon containing alloys

Silicon containing alloys show a substantial lowering of solidus temperature. Alloy 11 (Table 2) contains 2,100 ppm Si, and its composition is partially similar to alloy 2, but its melting range is 74°C.

The composition of alloy 32, that contains 600 ppm Si, is different from the composition of the other alloys, but it is presumed that the lowering effect of silicon on the solidus temperature is compensated by the effect of gallium on liquidus temperature, so the melting range (50°C) is still acceptable.

# 9. Conclusions

This study has been focused on practical results, even if some new hypotheses have been formulated on the mechanism of action of silicon in investment casting of gold alloys.

The following effects of the addition of alloying elements to the reference alloy have been observed.

- On the basis of the present results, indium has been considered unsuitable for these alloys, because it can form volatile oxides, lowers solidus temperature and widens the melting range, even at low concentration.
- For the moment the use of rhenium for grain refining has been set aside, because Re is difficult to introduce in the alloy. It is also difficult to prepare the master alloy, that requires the use of nickel. In yellow gold the presence of nickel must be declared when nickel concentration is higher than 0.05 %.
- A 10 to 20 ‰ zinc addition causes a general, substantial improvement of characteristics, particularly when coupled with silicon (range of 200-600ppm).
- Silicon gives very good results if its concentration is kept between 200 and 600 ppm, when also 10 to 20‰ zinc and 10 to 15‰ gallium (these max value require further investigation) and no more than 700 ppm iridium are present.
- Gallium, when used in conjunction with silicon, has an exceptionally favourable effect on the position of shrinkage defects in the castings. In our experimental case a 10% gallium content, in conjunction with a range of 200-600 ppm Si,

drives the shrinkage defect in the inner part of the castings.

• The concentration of iridium should be kept below 700 ppm, when a maximum of 600 ppm silicon is present. With higher concentrations, in some operating conditions (particularly, but not exclusively, with high melt and flask temperature) iridium silicides can form. These silicides cause the formation of low density hard spots that go to the outer surface of the castings, causing defects that are very difficult to remove.

Among the experimented alloys, alloys 28, 30 and 32 complied with all the above conditions. Alloy 32 is fully satisfactory also for colour requirements.

# 10. References

- Max Hansen and Kurt Anderko Constitution of binary alloys second edition
- ProGold Patent N° V2004A102 of April 30, 2004, "A red alloy for precious metal products with reduced defects occurrence"





TABELLA\_2





TABELLA \_ 4





TABELLA\_6





TABELLA\_8



TABELLA \_ 9