GOLD & ITS ALLOYS

Gold Alloys

Pure (24 carat) gold is a deep yellow colour (an orange shade of yellow) and is soft and very malleable. The coloured carat gold alloys range in gold content from 8 to 22 carats (33.3% - 91.6% gold) and can be obtained in a range of colour shades: green (actually a green shade of yellow), pale yellow, yellow, deep yellow, pink/rose and red. There are also white golds and even unusual coloured golds such as 'purple gold'. They all have different mechanical properties such as strength, hardness and malleability (ductility) and some alloys can be heat treated to maximize strength and hardness. There are gold alloys that are optimized for different manufacturing routes such as lost wax (investment) casting and stamping.

How can colour be varied and why do different gold alloys (an alloy is a mixture of two or more pure metals) have different mechanical and other properties? To answer these questions in depth requires a good technical knowledge of metallurgy. However, it is possible to give some simplified answers.

The Coloured Carat Golds

Almost all conventional, coloured carat golds are based on gold-silver-copper alloys, often with minor alloying additions. All three metals have the same crystal structure (face centred cubic, FCC) and so are compatible with each other over a large range of compositions. Typical minor additions include deoxidisers such as zinc and silicon, grain refiners such as iridium and cobalt and possibly metals such as nickel to strengthen the alloy. Larger zinc additions (about 1-2%) can improve melt fluidity and hence 'castability' in lost wax casting, as can silicon, resulting in better filling of the mould and better reproduction of surface detail. Even larger zinc additions (up to 10%) can improve malleability of certain carat golds, particularly 14 carat and lower, used for making jewellery by stamping from sheet. Additions of low melting point metals such as zinc, tin, cadmium and indium lower melting ranges and hence are used to make carat gold solders.

Colour

Gold is yellow and copper is red, the only two coloured pure metals. All other metals are white or grey in colour. The addition of a red colour to yellow, as every school child knows, makes the yellow pinker and eventually red. The addition of a white makes the yellow colour paler and eventually white. This principle of mixing colours is the same in carat golds. Adding copper to gold makes it redder and adding silver, zinc and any other metal makes gold paler. Thus, we can understand that lower carat golds, because we can add more alloying metals, can have a wider range of colours than the higher carat golds.
Thus at 22 carat (91.6% gold), we can only add a maximum of 8.4% of alloying metals and hence can only obtain yellow to pink/rose shades. At 18 carat (75.0% gold) and lower, we can add 25% or more alloying metals and hence get colours ranging from green through yellow to red, depending on the

Courtesy: World Gold Council

copper: silver plus zinc ratio. Thus at any given caratage we can vary the colour by varying the copper: silver plus zinc ratio. This can be demonstrated in the following table:

Effect of copper : silver ratio on colour

Type	Gold % wt	Silver %	Copper %	Colour
22 ct	91.6	8.4	-	Yellow
	91.6	5.5	2.8	Yellow
	91.6	3.2	5.1	Deep yellow
	91.6	-	8.4	Pink/rose
18 ct	75.0	25.0	-	Green-yellow
	75.0	16.0	9.0	Pale yellow, 2N
	75.0	12.5	12.5	Yellow, 3N
	75.0	9.0	16.0	Pink, 4N
	75.0	4.5	20.5	Red, 5N
14 ct	58.5	41.5	-	Pale green
	58.5	30.0	11.5	Yellow
	58.5	9.0	32.5	Red
9 ct	37.5	62.5	-	White
	37.5	55.0	7.5	Pale yellow
	37.5	42.5	20.0	Yellow
	37.5	31.25	31.25	Rich yellow
	37.5	20.0	42.5	Pink
	37.5	7.5	55.0	Red

Properties

Alloying additions affect other physical properties as seen in the next table:

Physical Properties of Typical Gold Alloys

Carat	**Composition %**		**Colour**	**Density g/cm3**	**Melting Range °C**
	Silver	**Copper**			
24	-	-	Yellow	19.32	1064
22	5.5	2.8	Yellow	17.9	995-1020
	3.2	5.1	Dark yellow	17.8	964-982
21	4.5	8.0	Yellow-pink	16.8	940-964
	1.75	10.75	Pink	16.8	928-952
	-	12.5	Red	16.7	926-940
18	16.0	9.0	Pale yellow	15.6	895-920
	12.5	12.5	Yellow	15.45	885-895
	9.0	16.0	Pink	15.3	880-885
	4.5	20.0	Red	15.15	890-895

As caratage reduces, the melting range and alloy density are lowered. But at any given caratage (gold content), the actual values vary according to the relative silver and copper contents.

Courtesy: World Gold Council

As well as affecting physical properties, alloying additions to gold generally increase the strength and hardness, with some reduction in malleability / ductility. The silver atom is slightly larger than that of gold, so alloying gold with silver gives a moderate improvement in strength and hardness. The copper atom is significantly smaller than that of gold and so it has a greater effect on strengthening gold than silver, as it distorts the gold crystal lattice more. Thus reducing caratage from 24 carats through 22 ct and 21 ct down to 18 carat gold results in stronger and harder alloys, as can be seen in Table 3. Beyond 18 ct down to 10, 9 and 8 carats does not have much further effect.

Mechanical Properties of Typical Gold Alloys

Carat	Composition %, wt.		Condition	Hardness HV	Tensile Strength N/mm2
	Silver	Copper			
24	-	-	Annealed	20	45
			Worked	55	200
22	5.5	2.8	Annealed	52	220
			Worked	138	390
	3.2	5.1	Annealed	70	275
			Worked	142	463
21	4.5	8.0	Annealed	100	363
			Worked	190	650
	1.75	10.75	Annealed	123	396
			Worked	197	728
18	12.5 0	12.5	Annealed	150	520
			Worked	212	810
	4.5	20.5	Annealed	165	550
			Worked	227	880

Table 3.2: Mechanical Properties of 18 Carat Golds

Composition, wt%			Hardness, HV		Elongation, %	
Gold	Silver	Copper	Annealed	Cold worked	Annealed	c.w.
75	25	-	36	98	36.1	2.6
75	21.4	3.6	68	144	39.3	3.0
75	16.7	8.3	102	184	42.5	3.2
75	12.5	12.5	110	192	44.8	3.3
75	8.3	16.7	129	206	47.0	2.6
75	3.6	21.4	132	216	42.0	1.5
75	-	25	115	214	41.5	1.4

c.w. = cold worked

However, copper-containing carat golds in the range of 8-18 carats can be hardened even further because of their metallurgy. Hard second phases can be precipitated out in the solid state as they cool below about 400°C, making the carat gold less ductile. Because of this, such alloys must be quenched in water after annealing to retain the single phase, ductile state if further working is required. This can be seen in the next table, Table 4.1

Courtesy: World Gold Council

Effect of Cooling Rate on 18 Carat Golds after Annealing at 650°C

Composition, wt%			Hardness, HV	
Gold	Silver	Copper	Slow cooled in air	Water quenched
75	25	-	56	56
75	22	3	90	88
75	17	8	138	136
75	12.5	12.5	160	160160
75	8	17	170	165
75	3	22	196	177
75	-	25	242	188

Special low temperature (ageing) heat treatments (typically 3-4 hours at 280 -300°C) can later be employed to give substantial hardening to such annealed and quenched alloys. This is known as age-hardening. In 18 ct red golds, the hardness can be doubled, as shown in Table 4.2!

Effect of Heat Treatment on 18 Carat Alloys

Composition %, wt		**Colour**	**Condition**	**Hardness HV**	**Tensile Strength N/mm2**
Silver	**Copper**				
12.5	12.5	Yellow	Annealed, quenched	150	520
			Aged	230	750
4.5	20.5	Red	Annealed, quenched	165	550
			Aged	325	950

As all goldsmiths know, working a metal makes it harder and stronger, as we can see in the previous tables, but if it is overworked, it will eventually fracture. So, they know that worked carat golds must be annealed to restore the soft ductile condition. Typical annealing temperatures for carat golds are given in the following table:

Typical Annealing Temperatures

Alloy	**Annealing temperature °C**	**Colour**
Pure gold, 24 carat	200	Black heat
21 - 22 carat	550 - 600	Very dark red
18 carat	550 - 600	Very dark red
14 carat	650	Dark red
White gold (palladium)	650 - 700	Dull cherry red
White gold (nickel)	700 - 750	Cherry red
Sterling silver	600 - 650	Dark red

White golds

Apart from copper, all other alloying metals to gold will tend to whiten the colour and so it is possible to make carat golds that are white in colour. White golds for jewellery were developed in the 1920's as a substitute for platinum.

Additions of any white metal to gold will tend to bleach it's colour. In practice, nickel and palladium (and platinum) are strong 'bleachers ' of gold ; silver and zinc are moderate bleachers and all others are moderate to weak in effect.

This has given rise to 2 basic classes of white golds - the Nickel whites and the Palladium whites. At the 9 carat (37.5% gold) level, a gold-silver alloy is quite white, ductile although soft and is used for jewellery purposes. White golds are available up to 21 carat.

There is no legal definition of what constitutes a 'white' colour in golds and hence trade description of white gold may not mean 'detergent white'. Many commercial white golds are not a good white colour.

Nickel white golds

Nickel alloying additions form hard and strong white golds up to 18 carat. They are difficult to work and suffer from socalled 'firecracking'. Most commercial alloys are based on gold-nickel-silver-zinc alloys with copper often added to improve malleability. This copper addition, of course, affects colour, and so such white gold alloys are not a good white colour - more a slight yellow/ brown tint, particularly if nickel content is also low. As a consequence, such white gold jewellery is normally electroplated with rhodium (a platinum metal) which is tarnish resistant and imparts a good white colour.

Unfortunately, many people, the female population especially, are allergic to nickel in contact with the skin and this gives rise to a red skin rash or irritation. The European Union countries have enacted legislation valid from the 20th January 2000 that limits nickel release from jewellery. Thus, in Europe, nickel white golds are being phased out and being replaced by palladium white golds. The USA is taking a more relaxed approach, requiring jewellery to be labelled as nickel-containing, and much jewellery in the West is now advertised as 'non-allergenic' or 'nickel-free'. [See Separate Information Sheet, "The European Directive on Nickel…." and the article in Gold Technology, No 28, Spring 2000, "Nickel gets under your skin"]. Some typical nickel white gold compositions are shown in Table 6

Typical Nickel White Golds

	Gold, % wt	Copper, % wt	Nickel, % wt	Zinc, % wt	Hardness Hv	Liquidus °C
18ct	75	2.2	17.3	5.5	220	960
	75	8.5	13.5	3.0	200	955
	75	13.0	8.5	3.5	150	950
14ct	58.5	22.0	12.0	7.4	150	995
10ct	41.7	32.8	17.1	8.4	145	1085
9ct	37.5	40.0	10.5	12.0	130	1040

Palladium white golds

Additions of about 10 -12% palladium to gold impart a good white colour. But palladium is an expensive metal, dearer than gold and it is also a heavy metal. Thus jewellery in such palladium white golds will be more expensive than identical pieces in nickel whites for 2 reasons: firstly, the cost of the palladium and secondly, the impact of density - palladium white golds are denser and so such jewellery will be heavier and also contain more gold. It is also more difficult to process as the melting temperatures are substantially higher.

Many commercial palladium white golds only contain about 6-8% palladium plus silver, zinc and copper. Some may even contain some nickel [so a palladium white gold is not necessarily nickel-free]. These may also have less than a good white colour and so may also be rhodium plated.

Palladium white golds tend to be softer and more ductile compared to nickel whites and so will not wear as well. They are available in all caratages up to 21 carat. It is not possible to have a 22 ct white gold, for example. Some typical compositions are given in Table7.

Typical Palladium Alloys

	Gold	Pd	Ag	Cu	Zn	Ni	Hardn Hv	Liq, °C
18ct	75	20	5	-	-	-	100	1350
	75	15	10	-	-	-	100	1300
	75	10	15	-	-	-	80	1250
	75	10	10.5	3.5	0.1	0.9	95	1150
	75	6.4	9.9	5.1	3.5	1.1	140	1040
	75	15	-	3.0	-	7.0	180	1150
14ct	58.3	20	6	14.5	1	-	160	1095
	58.5	5	32.5	3	1	-	100	1100
10ct	41.7	28	8.4	20.5	1.4	-	160	1095
9ct	37.5	-	52	4.9	4.2	1.4	85	940

Pd- palladium; Ag- silver; Cu - copper; Zn - zinc, Ni - nickel. [In wt %]

Alternative white golds

In the European Union especially, there is a demand for cheaper alternatives to white golds than the palladium whites which are nickel-free. Many new alloys are coming to market, most of which rely on manganese additions as the main whitener. Some are palladium-free and others are low palladium alloys. Chromium and iron are also be used as whiteners. They tend to be hard and more difficult to process. Many of these alloys are not a good white colour, requiring rhodium plating, and many suffer cracking problems and tarnishing.

The Caratage (Karatage) System For Gold Jewellery

Gold jewellery/ jewelry is usually described in terms of caratage (karatage), which is an indication of its gold content, for example 18 carat or 18K. Alternatively, the gold content can be described in terms of 'fineness', which is the gold content expressed in parts per thousand, for example 750 (which is 18 carat or 75.0% gold).

Since the price paid by the purchaser for gold jewellery is based on the amount of gold in it, it is important for the consumer to know how many carats (in USA – karats) of gold there is in the piece. Most jewellery worldwide is marked with the caratage or fineness. This may be part of a Hallmark on the jewellery (see Assaying & Hallmarking for the definition of a mark and hallmark).

Pure gold ('fine gold') is 24 carats (karats) and so 24 carats is theoretically 100% gold. In Chinese, it is also known as "Chuk Kam", meaning 'pure gold' and is defined as 99.0% gold minimum. Thus, there is a 1.0% negative tolerance allowed in this case.