

and modified working conditions may be necessary.

Type	Field of application	Working mechanism	Examples
1	Casting		
1a		High melting temperature, limited solubility in the alloy	iridium, ruthenium, (cobalt)
1b		High reactivity with oxygen, low solubility, formation of fine dispersed oxides	rare earth (yttrium), boron, barium, (calcium)
1c		1c Probably formation of intermetallic compounds	e.g. zirconium/boron cobalt/boron
2	Soft annealing	Formation of fine dispersions at annealing temperature	Cobalt, All Type 1 additions can also decrease grain size during softannealing

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Survey of additions

In the following, an attempt is made to classify additions which are mentioned in literature. However, this is somewhat arbitrary. Some additions can be placed in more than one class. Last but not least, not all the additions are really used in contemporary practice. The most frequently used additions are discussed later in more detail.

Improved castability (fluidity, form-filling) and prevention of scaling Most of the attempts made to improve alloys concern the casting properties. Investment (or Lost Wax) casting is nowadays the most important fabrication method for gold jewellery. It is also relatively susceptible to defect formation. There is a strong desire to improve the casting procedure and the quality of castings. One possibility for achieving this aim is the improvement of the properties of the alloys used in casting.

Castability and (improved) form-filling are almost synonymous terms. They are most influenced by two frequently used additions: zinc and silicon. It is not quite clear which property leads to improved form-filling. Most likely, it is the reduced interfacial tension. Both elements, as alloying additions, also reduce the formation of the dark porous copper oxide layer during the cooling period. The castings have a brighter surface as a result.

Deoxidiser

There is a considerable confusion about the use of deoxidisers. Principally, yellow gold alloys based on gold-silver-copper should not need deoxidising if

melted and cast under proper conditions. Copper oxide, the only oxide formed in this type of alloy, can be easily removed with slightly reducing conditions which can be achieved by use of a protective atmosphere, graphite crucible, or covering the melt with charcoal.

Of course, additions like zinc or silicon will reduce copper oxide with the formation of their much more stable oxides. However, these oxides can be even more detrimental than copper oxide. Especially in the case of zinc oxide, once formed, the oxide is difficult to remove from the melt. So, strictly, it is wrong to call these elements deoxidisers.

Phosphorous and, perhaps, boron act as a real deoxidiser. However, their effect is only beneficial if added in just the right concentration for removing oxygen (reducing the copper oxides). Any surplus phosphorous can be seriously detrimental, causing alloy embrittlement. In practice, it is almost impossible to find the correct concentration. Therefore, the use of such deoxidisers cannot be recommended.

Grain refiner

One of the disadvantages of yellow or red gold alloys is their relatively large grain (crystal) size and the pronounced dendritic structure in the as cast state. Deformed (cold worked) and soft annealed material would be improved if the grain size is reduced. Large grains are responsible for the orange peel surface effect, leading to increased polishing work, as well as lower ductility, for example. Thus grain refining is particularly desirable for wrought fabrication of jewellery and is important for investment cast jewellery.

The idea of grain refining is not very new. In the early 1970s, attempts were made to apply ruthenium additions as a grain refiner for castings. A later publication gives the results of a comparative study for the grain refining effect of different additions and combinations of additions (5). The following additions and combinations were among those tested: iridium, zirconium, cobalt, boron, yttrium, zirconium + boron and cobalt + boron. Barium was also found to be an effective grain refiner (3). In almost all cases, the additions were in the range of 0.005 to 0.05% per weight. Cobalt was added up to 0.5%. More detailed investigations showed that a