Dr. Christopher W. Corti
World Gold Council, London, UK

Christopher W. Corti is the Director of International Technology of the World Gold Council. He speaks regularly at the most important international conferences on gold and goldsmith technology. He has organized seminars on metallurgy of precious alloys and of jewellery technology for the World Gold Council all over the world.

Since less than a year, in the USA a team is working to answer some questions: what is a white gold? How can the boundaries of white be defined? When should a white gold be rhodium plated? Etc. Most likely, the final results of this study will be used to establish an agreed industry standard. Dr. Corti is the only european representative in this task force, as member of the world gold council. This presentation will explain the aim of the white gold task force, and will update the progress of the work.

Introduction

The popularity of white gold jewellery, particularly among the younger consumers of jewellery, and the impact of the EU Directive on nickel has led to a number of issues concerning white gold to be raised within the industry.

Prime among these is the issue of 'what is white' and associated with this is the use of rhodium plating. For good technical and economic reasons, many white golds are not a good white colour and need to be rhodium plated, a fact the jewellery purchaser is generally not made aware of. The validity of the nickel release test procedure as a basis for the EU legislation is also questioned, as conformance does not necessarily prevent the appearance of a skin rash on sensitised people. These issues and some of the marketing and legal implications are discussed.

The need to address these issues has resulted in a White Gold Task Force being established in the USA under the auspices of the MJSA and World Gold Council. Progress in the work of the Task Force and those of a UK initiative are discussed in terms of proposed recommendations on the technical issues in this paper as part of a worldwide consultation to reach an agreed international industry consensus.

The uniqueness of gold

Gold is unique among the jewellery metals and has been prized by man through the millennia for its warm yellow colour. In modern jewellery manufacture, however, its use is also unique in that carat gold jewellery can be made in a wide range of colour, from red through pink or rose to yellow, pale yellow and green to white. This colour variation is achieved by choice of alloying metals and is well documented (1).

The availability of white-coloured carat golds stems from the 1920s, when suitable white alloys of gold were developed as a substitute for platinum. Then, a colour match to platinum was the main objective. Since that time, white gold has grown in popularity. Today, a range of white gold alloys is available, with a colour that can be varied from a warm silvery white to a cold metallic grey, often with varying degrees of a yellow-brown tint. At a time of a strong white metal fashion, white gold has become a jewellery metal of choice, particularly among the younger female segment of the market, as evidenced by a recent World Gold Council market study (2).

What is a white gold?

The term “white gold” is used in a very loose and elastic way in the industry to describe carat gold alloys with a whitish hue and there is no agreed industry or legal definition in terms of colour. Historically, perhaps, it should mean close to the cold white colour of platinum. Many consumers believe a white carat gold is an alloy that is a metallic equivalent to snow-white. We in the industry know this is far from the fact. For very understandable technical and economic reasons, the term ‘white’ covers a large spectrum of colour that borders or overlaps pale yellow and even very pale rose. We often hide these off-white colours by rhodium plating. In some instances, manufacturers take a liberal view of what constitutes white gold, as shown in the example, Figure 1, which many consumers would find unacceptable.

Thus, the technology of white golds is particularly relevant in today’s market scenario. In my experience, consumers do not understand what white gold is nor are they aware of some of the issues that surround its use in jewellery. Many believe that the colour of the rhodium plating, which is what they see on many commercial pieces, is actually the colour of white gold! An interesting fact is that a major US upmarket branded jeweller that makes and sells white gold jewellery of a good colour in palladium white gold (see later for explanation) frequently rhodium plates the jewellery as ‘that is what the customer expects to see as the colour of white gold.’ Crazy but true! There is a consumer educational issue to be addressed here.

The aim of this presentation, therefore, is to briefly touch on the metallurgy and characteristics of white golds – what are they? – and then to focus on 3 important issues that impact our industry. The first of these concerns the description and definition of ‘white’ as applied to gold jewellery, the second is the use of nickel as a whitener and the third is the performance of rhodium plating on white gold jewellery. These should set the scene for the current industry initiatives on these and related issues and, hopefully, lead the industry to agree to the need for some standards relating to the definition of white as a colour in the context of gold jewellery, the use of rhodium plating and to review the use of nickel as an alloying metal in the context of the European legislation. The reasons why these issues are important will become evident later.

How is gold made white?

I am often asked questions on how to change the colour of gold. The answer is simple in concept; it is just as easy as mixing different colours of paint. Add red to yellow, in our case copper to gold and the alloy becomes redder. Add any white or grey metals to gold and it becomes paler and eventually white. In practice, of course the story is more complex, as we have other properties to consider if we wish to make jewellery.

Thus, white golds are made by alloying white or grey metals with gold. But different

alloying metals have varying degrees of whitening effect – or bleaching - on gold. As O'Connor has shown (3), nickel, palladium, platinum, iron and chromium are strong bleachers of gold, whilst other metals such as silver and zinc are moderate bleachers and others are weak. However, the use of many of these potential whiteners is inhibited by considerations of their metallurgy in gold alloys and their effects on mechanical properties. I do not intend to go into detail on these effects as they have been well covered in several excellent reviews of white golds, published in Gold Bulletin & Gold Technology journals and the Santa Fe Symposia, for example (4-7).

Commercial white golds

In practice, 2 classes of white golds have been commercially developed over the years, the nickel whites and the palladium whites, where nickel or palladium are used as the primary whiteners. To complicate the situation, hybrid alloys containing both nickel and palladium are also commercially available. At the low carat end, gold-silver alloys are a reasonable white colour and are commercially used. More recently, as we shall see, there has been a trend to develop alternative white golds that are nickel- and palladium-free. In general, white golds are available at all caratages up to 18 carats, with even a 21 carat palladium white alloy commercially produced in the Middle East. It is not possible to make 22 or higher carat white golds.

Nickel white golds

Most nickel white golds are based on gold-nickel–silver-zinc alloys, probably with some copper additions too to improve workability. High nickel (>12%) alloys are a good white colour but are extremely hard and difficult to work. Their metallurgy is also complex with a major immiscibility gap, resulting in 2 phase alloys. This can result in nickel whites yellowing in colour over time. Consequently, many commercial alloys are thrifted in nickel, with copper added to produce alloys that are more workable. However, this results in a degradation of the desired white colour to give alloys with a yellow-brown tinge and such alloys are usually rhodium-plated.

Palladium white golds

The palladium white golds are based on gold-palladium-silver-zinc alloys with possibly some copper and nickel added to improve mechanical properties. High (>12%) palladium alloys have a good white colour, are soft and easy to fabricate, but have much higher melting ranges, making lost wax (or investment) casting more difficult, and are more dense than their nickel white equivalents. The high cost of palladium and its effect on density results in white gold jewellery that is more expensive than nickel white or yellow gold jewellery against which it tends to compete on price. Consequently, many commercial alloys are thrifted in palladium and often contain some copper, again resulting in a degradation in colour and the need for rhodium plating of the jewellery.

Colour and rhodium plating

For both types of white golds, the relationship between colour and alloying content

for 18 karat white golds has been summarised by Susz and Linker (8), Figure 2. What is evident is that many commercial white gold alloys do not have a good white colour and this deficiency is overcome by rhodium plating the jewellery, a situation legally recognised and accepted in many countries, including those with strict hallmarking regulations.

However, there is generally no legal requirement to declare to the consumer that an item is rhodium-plated nor to specify a minimum level of plating in terms of thickness or wear resistance. Thus the consumer is generally in ignorance that the white colour she sees is that of rhodium rather than the underlying white gold alloy. This lack of requirement to inform the consumer if an article is rhodium plated is also an issue for the jewellery industry and falls under national consumer legislations (such as the Trades Description Act in the UK). It is surprising that litigation on this point has not already arisen.

Nickel versus palladium white golds

I noted a moment ago that white carat golds based on palladium are less competitive against nickel-whites and the coloured karat golds on price. Consumers tend to expect white carat gold jewellery to be similar in price to its equivalent in yellow gold. If price dominates, as in the mass markets, then thrifted nickel, hybrid nickel-palladium or alternative white golds will tend to be preferred unless other requirements intervene.

At the high end of the market, of course, such intrinsic price differences are less important and high palladium white golds, with good colour, can compete successfully. For example, in Japan, white golds compete head on with platinum jewellery (rather than yellow gold) and 18 carat white golds, alloyed with up to 20% of palladium and platinum combined, giving good white colour and reasonable workability and strength, are able to compete effectively with the more expensive platinum jewellery.

Thus, it is “horses for courses” when it comes to selecting white gold alloys for jewellery manufacture. Where good white, nickel-free golds are demanded, high palladium whites are the natural choice (but see later re- ‘alternative’ white golds).

The nickel skin allergy problem

There is one major problem with white golds that contain nickel. A sizeable proportion of the population, particularly women, have developed an allergy to nickel when it is in contact with the skin. In jewellery, this problem relates mainly to white golds and gold-plated fashion jewellery where there is a nickel underlayer. It also applies to zippers, other non-precious jewellery and body piercings, buckles, watchstraps as well as coins. Some examples of the allergy on sensitised women which results in a red rash on the skin are shown in Figure 3, taken from reference 9.

As the audience here will know, in Europe, certain countries such as Sweden and Germany began to introduce legislation against use of nickel in jewellery and other items during the 1990s. This was seized on by the European Union who introduced an EU Directive that required Member countries of the European Union to introduce national legislation. These national laws came into effect on the 20th January 2000, i.e 4 years ago.

The laws apply to any item, not only jewellery, that comes into 'direct and prolonged contact with the skin'. There are 2 aspects to the requirements:

1. Ear Posts (including posts inserted into other parts of the body) that are *inserted into the wound during the healing period* (epithalisation) following piercing:
   The law prohibits the use of nickel in posts inserted into the wound during the healing period, if the concentration of nickel in the post is 0.05% wt. nickel or more. The UK guidelines suggest that other contacting surfaces of earrings are included here.

2. Parts of jewellery and other items *coming into direct and prolonged contact with the skin:*
   (a) The **release** of nickel above 0.5 microgrammes per square centimetre per week is prohibited.
   (b) This release rate is not to be exceeded for a period of **at least 2 years** of normal use of the product

We should note that **nickel release** is defined in terms of a Standard Test for nickel release, which is based on immersion in a salt solution to simulate human sweat. Interpretation of test results is also subject to a x10 "adjustment" factor. There is also another Standard procedure for wear designed to simulate '2 years normal wear' prior to release testing. For those wanting more detailed information, I recommend the article by Rushforth (9).

Similar laws on nickel exist in Japan, China and some other countries. In the USA, such laws have not yet been enacted; the current requirement is for jewellery containing nickel to be labeled with a health warning.

The consequences of the EU Directive on nickel

In Europe, there has been a distinct move away from nickel white gold, perhaps not surprisingly. The obvious alternative is palladium white gold, but the additional cost has been exacerbated over the last year or two by the phenomenal rise in the palladium price to over $1000 per troy ounce until its fall to more normal levels late in 2002. Nevertheless, it remains an expensive option for the mass market.

The hybrid nickel-palladium whites are an alternative where nickel contents are held down to levels that enable the alloy to meet the nickel release test requirements and

where palladium is thrifted to low levels too. However, there is still a major problem: Simply passing the EU nickel release test is NO guarantee that the wearer of the jewellery will not suffer from the allergic skin reaction, as many manufacturers and retailers have found to their cost.

Consequently, many retailers and wholesalers are stipulating that they want completely nickel-free jewellery to avoid the potential litigation that may arise. This has put pressure on alloy developers to come up with alternative white gold formulations that are nickel-free and, ideally, palladium-free as well.

This pressure is also being felt in the USA and other countries outside of Europe, partly due to increasing consumer awareness. A 'health warning' label tells consumers that a problem exists, of course.

Alternative white golds

Many alloy producers are introducing 'alternative' nickel-free white gold compositions onto the market. Most of these are low palladium content, with some claimed to be palladium-free. Many are based on the use of manganese as the principal whitener, with possibly some iron or chromium as well.

In my experience, many of these alloys are not entirely satisfactory. They can be difficult to work or to investment cast, with a tendency to crack. They tend to tarnish and often have a poor white colour, so requiring rhodium plating. Some are distinctly yellowish-brown in colour. Developing such alloys with a satisfactory combination of colour and properties is a difficult task and inevitably, the alloy developer has to make some compromise. Whether these alternative golds will endure in the market is debatable.

White Golds: The Issues

1. The Colour Issue: What is white?

The issue of colour is important. In most countries, rhodium plating of yellow gold and passing it off as white gold is not allowed and is considered fraudulent. Likewise, if one rhodium plates a pale yellow gold, surely it is also fraudulent to call it a white gold. But if we develop a so-called white gold that is yellowish in colour, and call it white, where do we stand? Where is the border between fraud and non-fraud? That is the problem. There is no guideline or standard! It leaves jewellers open to litigation for passing off something that is not white in the consumer's eyes. The situation creates a real problem, for example, for white gold alloy developers trying to balance colour with mechanical properties and cost. A practical alloy must have adequate fabricability and competitive cost, so colour is invariably compromised, particularly if it can be hidden by rhodium plating. The question is how far can the alloy developer stray from a perfect white colour and still claim his alloy as a white gold.

This problem arises because we do not have a definition of the colour 'white' as applied to white gold jewellery. And, of course, we can legally hide an inadequate colour by rhodium plating. As I said earlier, the consumer's expectation is often not matched in practice. That is fine, if the consumer can see the jewellery's true colour, but if we rhodium plate it, how is she to know?

Of course, there is a colour standard for a white gold outside of ISO 8654/EN28654, the 8N standard for a 10% nickel white (which would fail the EU nickel directive). But we need to define an area of colour for white that applies to all types of white gold alloys, not just a single point.

2. Rhodium Plating Issue

Another issue arising from this is the quality of rhodium plating, if used. Platings that wear off in a matter of several weeks or months are not acceptable, if we see our product as a quality product that projects gold's image of preciousness and everlasting quality. We know that the integrity and performance of rhodium plating is sensitive to bath contamination and surface cleanliness and preparation as well as thickness of the plate. The industry needs to consider some specification for rhodium plating based on some test of minimum acceptable performance.

3. The Nickel Allergy issue

As I have already indicated, the nickel allergy issue only affects Europe, China and Japan from a legislation viewpoint at the present. However, a number of questions arise:

A] Will similar legislation be enacted in the USA and elsewhere? There is a body of opinion in the US industry that thinks it will be, sooner or later. Whether it is or is not, we are still faced with the problem. Consumers are increasingly aware and, in this litigious society, which retailer or manufacturer wants to risk being sued for damage to health? Should the US industry adopt a voluntary code of practice on this issue? The images of the industry and of gold jewellery are involved in this issue too. It is arguable that the USA needs a voluntary code of practice that promotes nickel-free products. Just labelling jewellery product with a health warning is not sufficient.

B] How good is the EU legislation? A major problem is that the EU Directive is based on a standard artificial laboratory test for nickel release, the results of which are then subject to an arbitary 'adjustment factor' X10 (9). As published work by Leach & Garner has shown (10), the Test is not reliable nor is it consistent. The EU legislation is not built on firm foundations! This should give us much cause for concern. We do need to rethink this problem and come up with an improved test procedure. This requires the industry to work together to address this problem. Certainly, it is questionable whether the legislation does protect sensitised wearers of jewellery from an allergic reaction, as noted above. So what is the point of it?
Clearly, retailers and manufacturers will want to be assured that their white gold jewellery is nickel-free. It is interesting that the Birmingham Assay Office in the UK has introduced

a due diligence quality assurance scheme, called 'AnchorCert - Nickel Standard' to protect companies against such litigation in the UK. This is also available to jewellers in the USA through its local New York office, The American Assay & Gemmological Office.

How do we define the colour 'white'?

I cannot raise the issue without making some suggestion on how we might approach a solution to the problem as a basis for debate.

Firstly, to do this, we need to be able to specify colour in some repeatable and quantifiable way. Fortunately, this is an established procedure – the CIELab system for measuring colour (which is done on a colour photo-spectrometer instrument). This has 3 co-ordinates. Co-ordinate L measures the degree of lightness from 0 which is black to 100 which is white and is a measure of reflectivity. The co-ordinate 'a*' measures the red – green component of colour and the co-ordinate 'b*' measures the yellow – blue colour component. A perfect pure white would have L =100 and a* and b* =0. It is important to recognise that practical measurements must be done under standard illumination conditions. For jewellery, this is recognised as Illuminant 'C' or its close companion, 'D65'.

In attempting to define the boundaries of white, we can take one of two positions:

A] We only define the area of acceptable white for gold as that which has a good colour and does not need rhodium plating.

Or

B] We define a much broader area of colour space to embrace 'whites' that do need to be rhodium plated (but are not 'yellow').

A further option is:

C] To define 2 (or more) concentric areas relating to A] and B] above, as shown schematically in Figure 4. This would mean we effectively have two grades of white gold – a 'premium' grade that does not need plating and a 'standard' grade that does need rhodium plating. There are marketing implications to this approach. The 'premium' grade would include the more expensive, high palladium whites.

Whatever stance we take, the problem is where do we draw the boundaries?

The MJSA/WGC Initiative: The White Gold Task Force

The issues relating to white gold raised in this article were first discussed publically in a Round Table meeting on white gold held at Expo 2003 in New York under the auspices of the MJSA. At this discussion, a need for action was agreed by the industry representatives present. The MJSA, together with the World Gold Council,

set up a US-based industry task force to address the issues. The White Gold Task Force (WGTF) is initially only considering the technical issues, with the marketing and consumer education issues to be addressed separately at a later time.

The objective of the WGTF is to make a recommendation on defining the colour white and, coupled with this, a recommendation on a minimum standard for rhodium plating. These will be recommended as industry guidelines and may lead to an international ISO standard. The WGTF is very clear that such draft recommendations must have the agreement of the industry worldwide, and so consultation through international and national jewellers organisations is planned so that international agreement can be achieved. Some proposals for defining white have already been made by 2 European companies and input from others is welcomed by the WGTF. It is planned that the initial recommendations will be available in late February 2004.

In the UK, the Birmingham Assay Office, with Cookson Precious Metals Ltd, has also taken up the challenge from the Round Table meeting and is leading a small retail-led committee to consider a definition of white in terms of what can be easily used practically by retailers and manufacturers without access to sophisticated colour measurement spectrophotometers.

One of the interesting facts to emerge from discussions with this committee and others I have had with retailers is that it is rare for a retailer to specify colour in any quantifiable way when ordering white gold jewellery from a manufacturer and this experience is also echoed by gold alloy suppliers.

Progress to date

Both the WGTF and the UK committee have measured many samples of white golds for whiteness. The UK committee reported sooner, pre-empting the USA Task Force, and has proposed some definitions for white golds. Supported by Gretag-MacBeth, the colour measurement company, they have made 2 important proposals (12):

- That whiteness in white golds can be defined by a single parameter, the ASTM Yellowness Index:1925 (see Table 3 for definition). This is the best parameter although not perfect. This index was originally developed for the plastics industry many years ago and is well established. Whiteness can also be defined in terms of the 3 CIELab co-ordinates, L, a* and b*.
- That 3 grades of white gold be defined:
  a) Premium white grade – *these alloys have a good white colour and do not need rhodium plating.*
  b) Standard grade – *rhodium plating is optional for these alloys*
  c) Off-white – *such alloys need to be rhodium plated*

Any alloys falling outside of these three grades are classed as non-white. In terms of the Yellowness index, these grades can be defined as follows, Table 1:

Table 1 Proposed grades of white in white golds (UK group recommendation)

Grade	Yellowness index value
Premium	< 19.0
Standard	19.0 – 24.5
Off-white	24.5 – 32.0
Non white	>32.0

These definitions can also be translated into a CIELab plot or 'map', with the colour space boundaries for each grade drawn on, as shown in Figure 5.

In terms of a practical system for use by retailers and manufacturers, Munsell colour charts are proposed which enable comparison of white gold jewellery to the colour grades.

Subsequently, the US WGTF has met and considered their measurements on many white gold samples. They have agreed with the approach taken by the UK group and accepted their proposals for whiteness index and the 3 grades, with the following limitations which recognises the imperfection of the ASTM Yellowness Index:D1925, Table 2 in this application.

Table 2 Definition of white in quantitative colour terms (WGTF recommendation)

In line with the UK proposals, the following definitions for white gold are recommended:-

Measurement conditions
Illuminant C (D65 is a close approximation), observer angle 2°, specular and ultraviolet components included. Samples polished to 6 micron finish.

Degree of whiteness
As a single parameter, the ASTM Yellowness Index:D1925 is the best parameter for describing the degree of whiteness of white golds.

The Yellowness Index (YI) is calculated from the CIE tri-stimulus values, X,Y & Z. The scale is linear: as the number decreases, the alloy is whiter.

$$YI = [100\ (1.28X - 1.06Z)/Y]$$

Limiting conditions
This index does favour white colours with a green tint versus those with a red tint, so a limit of + 3.0/-. 3.5 on the CIELab a* value (red-green axis) is proposed. Also, all whites should have a minimum brightness value L of 75.

Suitable Munsell colour charts are being developed by the Munsell Laboratory, Gretag-MacBeth Inc., based on the 3 grades proposed.

With regard to rhodium plating performance, the WGTF has decided not to make a recommendation at this time. Likewise, no decision on the nickel issue has yet been made.

Next steps

The WGTF is recommending that its proposals are trialled for 6 months to ensure they are workable and meet the industry needs. The practical use of these definitions awaits development of suitable Munsell colour charts, as noted above.

A trade Guidance document has been drafted and agreed. The definition and grades will be a voluntary guideline only at this stage for the US industry. Implementation is expected to commence in January 2005 and be fully implemented by 2006.

During this period, there will be consultation with the industry both in the USA and overseas, via CIBJO and the national bodies to reach international agreement.

There are also marketing and consumer/trade educational implications, as discussed earlier, to the definitions that need to be considered.
These will be considered in the next period.

Concluding remarks

The significant technical issues concerning white gold jewellery that impact its market quality and consumer image have been discussed. There is a consensus of agreement within the industry for action and this has led to the setting up of an industry-led White Gold Task Force in the USA to consider them and make recommendations on realistic solutions. A similar UK technical committee has paralleled this work, and both are now working together.

Significant progress has been made by both UK and USA groups. Some proposals have been made for defining white and setting some boundaries for 3 grades of acceptable white gold. It is anticipated that these recommended solutions will form the basis of voluntary codes of practice, possibly official standards at a later date, accepted on an international basis. This will entail worldwide consultation to obtain international agreement.

Some associated issues of consumer's right-to-know and education and white gold marketing approaches have been highlighted.

Acknowledgements

The author acknowledges the many contributions and discussions within the industry that have helped to define the issues and assisted in the preparation of this article. Thanks to the JTF for inviting me to speak and also to the World Gold Council for their support and permission to publish.

References

1. See, for example, (1) T.K.Rose & W.A.C Newman, “The Metallurgy of Gold”, 7th ed., publ. Charles Griffin & Co Ltd, 1937, reprinted by MetChem Research Inc, 1986, p 56-59
   (2) Gmelin’s Handbuch der Anorganischen Chemie,, 8th edition, System No 62, “Gold”, 1954, p954-956.
2. Internal Report: Market Segmentation Study in 5 Major Markets, World Gold Council, 2003
3. G.P.O’Connor, “Improvement of 18 carat White Gold Alloys”, Gold Bulletin, 11(2) 1978, p35-39
4. G.Normandeau, “White golds: A review of commercial material characteristics & alloy design alternatives”, Gold Bulletin, 25(3), 1992, 94-103
5. G.Normandeau & R.Roeterink, “White golds: a question of compromises”, Gold Bulletin, 27(3), 1994, 70-86
6. P.Rotherham, “White golds – meeting the demands of international legislation”, Gold Technology No 27, November 1999, 34-40
7. V.Faccenda, “On nickel white gold alloys: problems & possibilities”, Proc. Santa Fe Symposium, MetChem Research Inc, May 2000, 71-88
8. C.P.Susz & M.H.Linker, “18 carat white gold jewellery alloys”, Gold Bulletin, 13(1), 1980, 15-20
9. R.W. E. Rushforth, “Don’t let nickel get under your skin”, Gold Technology No 28, Spring 2000, 2-10
10. G.Raykhtsaum & D.P.Agarwal, “Nickel release tests: how well do they work?”, Proc. Santa Fe Symposium, MetChem Research Inc, May 2001, 375-384; also: Gold Technology, no 32, Summer 2001, 2-6
11. G.Raykhtsaum & D.P.Agarwal, “Surface finish effects on color measurements”, Proc. Santa Fe Symposium, MetChem Research Inc, May 1990, 147-163
12. S.Henderson & D.Manchanda, “Report on measurement and classification of white gold”, December 2003. Internal report to the UK (Birmingham Assay Office) technical committee on white gold.

Figure 1 Example of a white gold earring with the rhodium plating removed to reveal the poor colour of the underlying 'white' gold (photo: courtesy Stern-Leach)

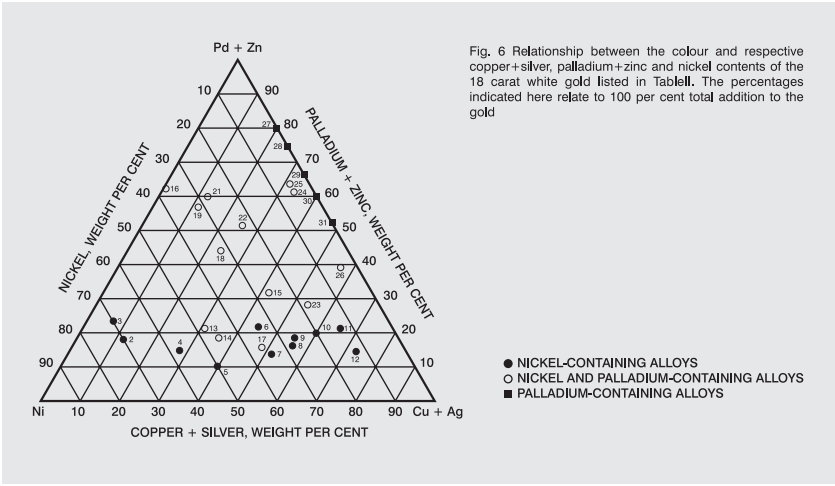

Fig. 6 Relationship between the colour and respective copper+silver, palladium+zinc and nickel contents of the 18 carat white gold listed in TableII. The percentages indicated here relate to 100 per cent total addition to the gold

Figure 2 Relationship between colour and alloy composition for 18 carat white golds, (figure 6, taken from Susz & Linker (8)).

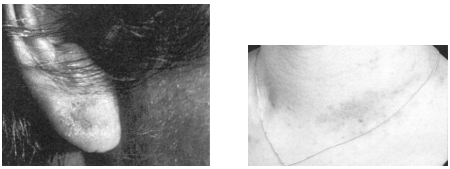

Figure 3 Examples of skin rash due to nickel allergy, taken from Rushforth (9).

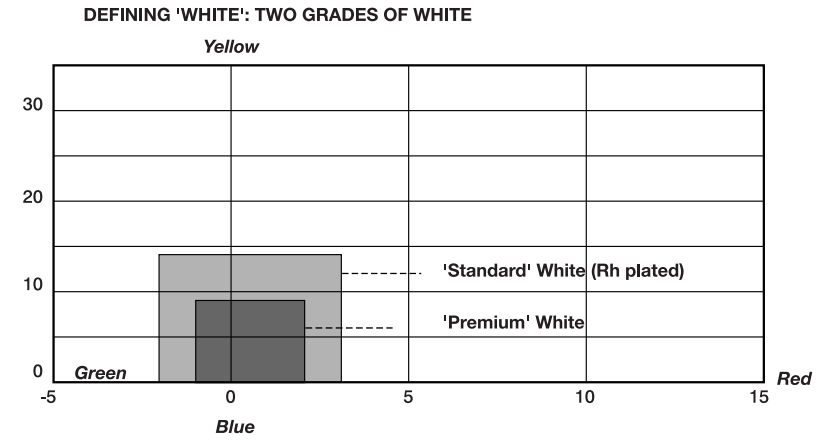

Figure 4 Schematic: Defining 2 areas of white quantitatively in CIE-Lab colour co-ordinates. Premium grade – small area of good alloy colour where rhodium plating is unnecessary. Standard grade – larger area of poorer whiteness where rhodium plating may be required.

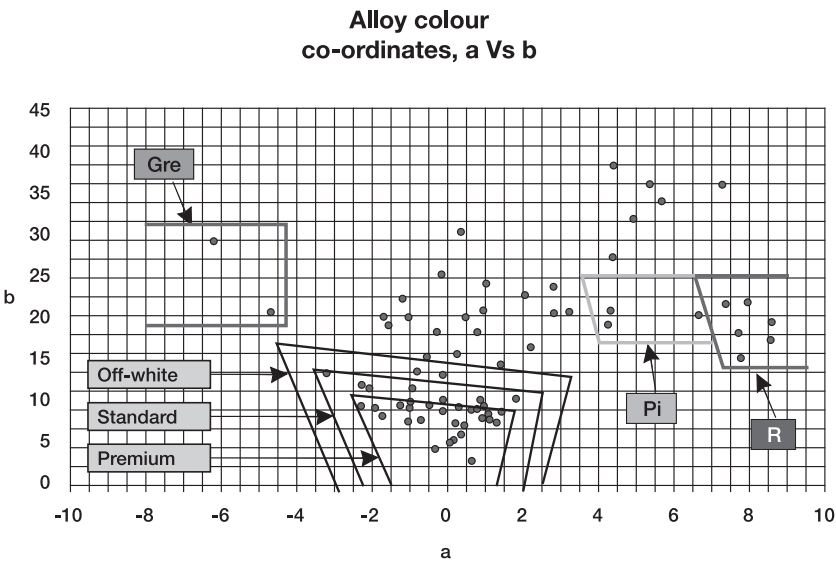

Figure 5. The proposed grades of white plotted in CIELab co-ordinates, a and b* (from reference 12)*