



BUREAU OF INDIAN STANDARDS

SEPTEMBER, 2021

BIS HALLMARK – GREEN TESTS FOR YELLOW METAL

Bureau of Indian Standards, the National standards body of India, was established under the BIS Act, 1986, to construct an internationally accepted mechanism to protect consumers and foster competition.

BIS launched the voluntary hallmarking scheme in the year 2000, striving to ensure the empowerment of all citizens with good quality precious metals and to fill the regulatory vacuum in the Indian gold market. In order to ensure purity in Gold Jewellery, hallmarking was made mandatory from June 23, 2021. Assaying and hallmarking centres (AHCs), one of the abutments to the hallmarking scheme, are responsible for the accurate analysis of the composition of materials at all times.

There are various issues faced in the implementation of mandatory hallmarking and it is thus important to understand how hallmarking is implemented in other parts of world. The fire assay method being the stalwart among analytical techniques, is used worldwide, including in India. The process makes it possible to obtain minute quantities of concentrated precious metals, but the process also gives off toxic lead fumes, which pollute the environment. Recently, CPCB issued guidelines covering modalities for environmental clearance to mitigate the negative impacts of the test method which caused a stir and left the AHCs uncertain. The notification in its wake has given the country an impetus to align its plans with the sustainable growth avenues currently at its disposal and seek clean and green alternative approaches for gold testing without compromising accuracy. How AHCs will adapt to these recent regulations is a question to answer.

BACKGROUND

Go Green: CPCB Advisory

The Hon'ble NGT, vide order passed on 18.11.2019 issued the advisory that henceforth all the gold assaying and hallmarking centers in the country shall obtain the consent to establish/consent to operate under Water (Prevention and control of pollution) Act 1972 and Air (Prevention and control of pollution) Act 1981 of the state pollution control boards. These units shall also obtain authorization under hazardous and other waste (Management and transboundary movement) Rules 2016. NGT also advised BIS to explore other green method for Gold and Silver testing.

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CPCB in their guidelines also mentioned the harmful effects of the traditional Fire assay method such as generation of lead oxide and nitrous fumes during parting.

Subsequently, CPCB formulated guidelines for BIS to make mandatory to have a copy of consents issued by SPCBs/PCCs under Water Act 1974 & Air Act 1981 and Authorization certificates while issuing the BIS certificates. Gold assaying and hallmarking centres have thus been put in orange category and in many states the centres are finding it difficult to get consent from state pollution control boards as the assaying centres are mostly present in the crowded jewellery market.

THE DILEMMA:

Due to this order, many of the assaying and hallmarking centres have been put under suspension by BIS which is not only be a monetary loss to the promoters of centres but also it is deterrent in the implementation of mandatory hallmarking as the number of assaying and hallmarking centres will decrease and the available centres may not be adequate to test the jewellery.

Mr Venkat Rao, Venkatesh Hallmarking Centre is facing a crisis situation as SPCB refused to give them permission to operate in city limits. Since their work was listed under orange zone, it has to be set up outside the limits of Hyderabad municipality or shut down the centre. The recognition of the centre was also put under deferment by BIS.

Mr Khanna, Mandovi Jewellers is also under discussion with other jewellers in the market who would be impacted with this order. Now, the Jewellers would have to take their Jewellery almost on a daily basis to the Assaying Centres which are located far away from their business market. This would add to the risk and the transport cost. Further, they would require additional insurance to cover the risk involved in such transportation. Also, there would be an additional time lag in delivering the jewellery to the customers which would lead to their dissatisfaction. This would lead to additional costs which would affect their business.

INTRODUCTION

BIS Hallmarking scheme

Hallmarking scheme for gold jewellery/artefacts was started by Bureau of Indian Standards (BIS) in the year 2000 to protect the consumer against cheating, develop export competitiveness and make India a leading market for gold jewellery in the world.

Hallmarking is the accurate determination and official recording of the proportionate content of precious metal in the jewellery/artefacts or bullion/coins.

Venkatesh Assaying and Hallmarking centre

Venkatesh Assaying and Hallmarking centre (popularly known as VAHC) was established in 2018 with an aim to serve Jewellery Industry so as to maintain and upgrade its quality. VAHC established a Management System for Quality, administrative and technical operations conforming to IS 15820: 2009.

The centers are equipped with latest test equipment's, well trained & professional staff from this industry and the mindset to do quality work.

Mr. Venkat Rao is a first-generation entrepreneur who has done his graduation in Chemical engineering and was working in a chemical factory at Ankleshwar. On advice of one of his jeweller friend, he has left his job and invested all his life time saving in setting up of Venkatesh Assaying and Hallmarking centre in Hyderabad city near to jewellers market. He has even taken 40 Lakhs loan from a bank. The centre was provided by licence by BIS in 2018 has been operating satisfactorily for 2 years.

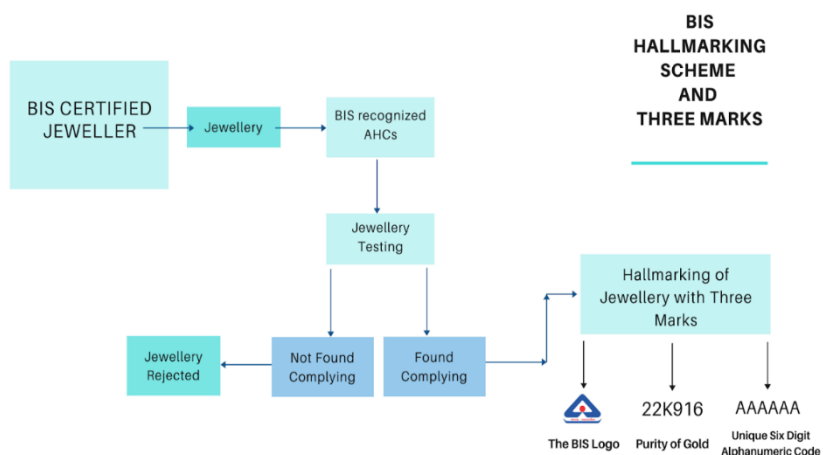
Mandovi Jewellers:

Mandovi Jeweller is India's leading fine jewellery discovery platform focusing on giving quality jewellery with 100% assurance. It was a family owned business led by Mr Khanna and his sons. Shining bright with a young team focused on innovation, customer happiness and transparency, Mandovi Jewellers addresses the growing demands of today's always on-the-go consumers to discover, explore, buy and know more about their jewellery. Their policies provide easy returns, free shipping, BIS Hallmark, 100% certified jewellery, life-time exchange, best and transparent prices and unique designs. They have multiple centres across Hyderabad. The jeweller first got BIS registration to sell BIS Hallmarked jewellery in 2008 which got renewed again in 2018.

CURRENT HALLMARKING PROCESS AND ASSOCIATED TEST METHODS

The two main pillars of BIS hallmarking scheme are jewellers and assaying and hallmarking centres. The jeweller registers with BIS for selling hallmarked jewellery and sends the jewellery for hallmarking to BIS recognized assaying and hallmarking centres. Assaying and hallmarking centres are the centres where the jewellery is tested. The assaying and hallmarking centres tests the jewellery and if the jewellery is found complying to the requirement of BIS standard, the jewellery is hallmarked. This hallmarked jewellery is then returned back to jeweller. The hallmarked jewellery is marked with three marks.

Exhibit 1 of BIS hallmarking scheme and three marks

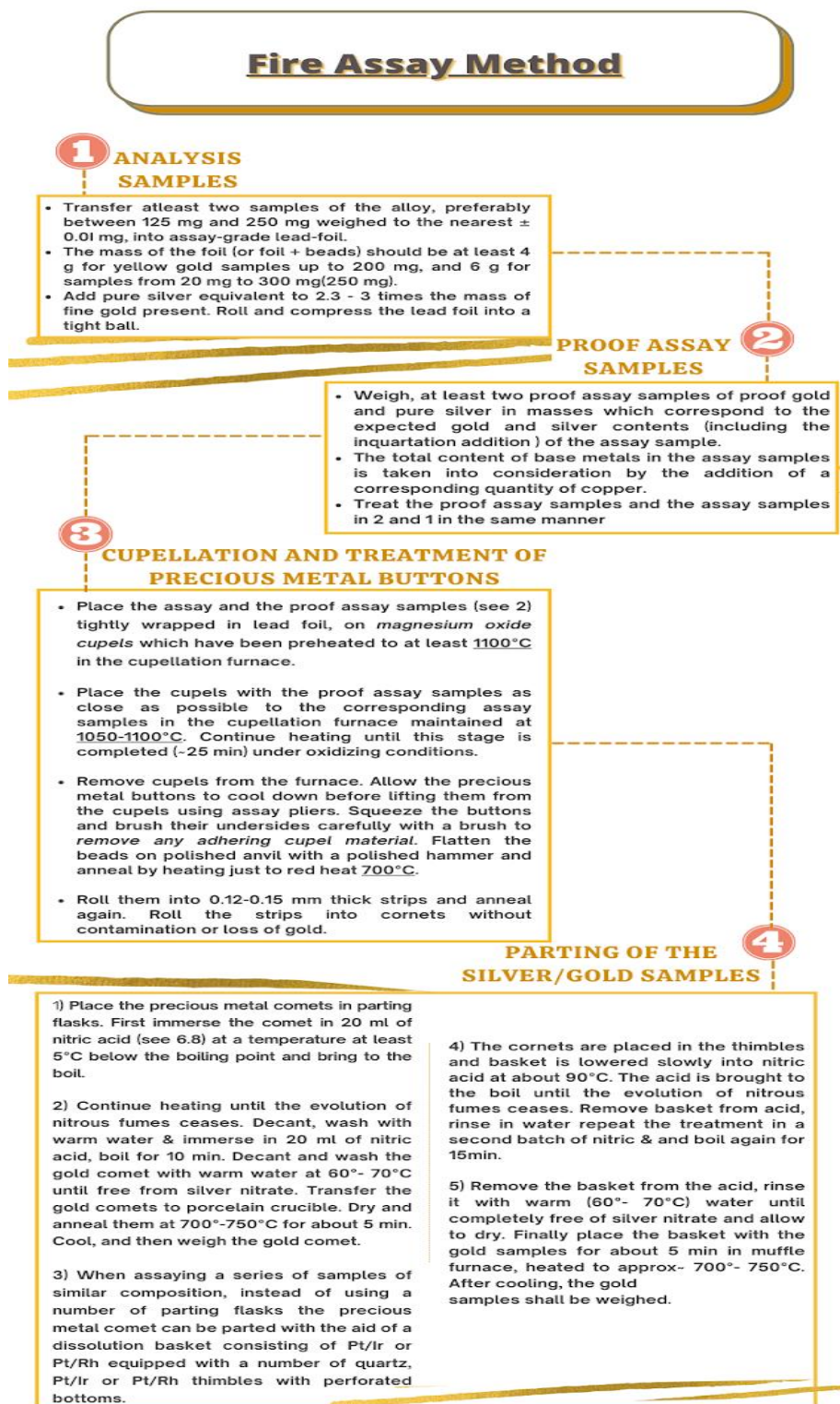


Quality control order for mandatory hallmarking of gold jewellery/artefacts has been issued on 23 June 2021 for 256 districts where there is atleast one assaying and hallmarking centres.

At present there are about 70000 jewellers registered with BIS for selling hallmarked jewellery and there are about 950 assaying and hallmarking centres recognized by BIS for testing the jewellery before putting hallmark on the jewellery. Jewellers represented for various implementation issues of mandatory hallmarking. Indian standard IS 15820:2009 is the basis for recognition of assaying and hallmarking centres. The various steps followed in an assaying and hallmarking centre are given below as **Exhibit 2**.



In addition to other tests, the standard specifies a Fire Assay test for Assay and Hallmarking of gold, following the procedure prescribed in the method IS 1418: 2009 (Assaying of Gold in Gold Bullion, Gold alloys and Gold Jewellery/Artefacts: Cupellation- Fire Assay Method.). The process flow chart of fire assay method is given in **exhibit 3** given below.



As can be seen from the exhibit lead is used in the process and lead fumes are generated in cupellation. These fumes are then passed in the scrubber where they are dissolved in water. Also, nitric acid is used in parting which needs to be disposed of.

ISSUE/CHALLENGES

The recent NGT Order has identified AHC Centre as polluting Industry. Currently, AHC centres and the Jeweller market are located nearby which ensures easy transfer of jewellery samples amongst the jewellers and the AHCs. However, due to the recent NGT order, the AHCs are marked as polluting Industry and thus needs to shift their premises from the main jeweller market to the outskirts of the city or strict compliance with NGT Order.

As stated earlier, fire Assay (Cupellation) is the standard reference technique against which all other techniques may be compared. Despite its age, it remains the most accurate method but the recent NGT order to mitigate the polluting nature of the fire assay method has created a lot of uncertainties among the AHCs. The guidelines have impelled them to seek and settle for alternative methods with appropriate accuracy but the techniques available with accuracies bordering the fire assay process are costly and not easily available. Another process approach to tackle this situation for the AHCs is the scheme of BIS for setting up an offsite center wherein the main center can be in Industrial area complying with NGT/**CPCB norms**. This too has roadblocks, one of them being the additional investment required of around 30-40 Lakhs. The customers will also be dissatisfied as the whole transfer process policy would add to the delay.

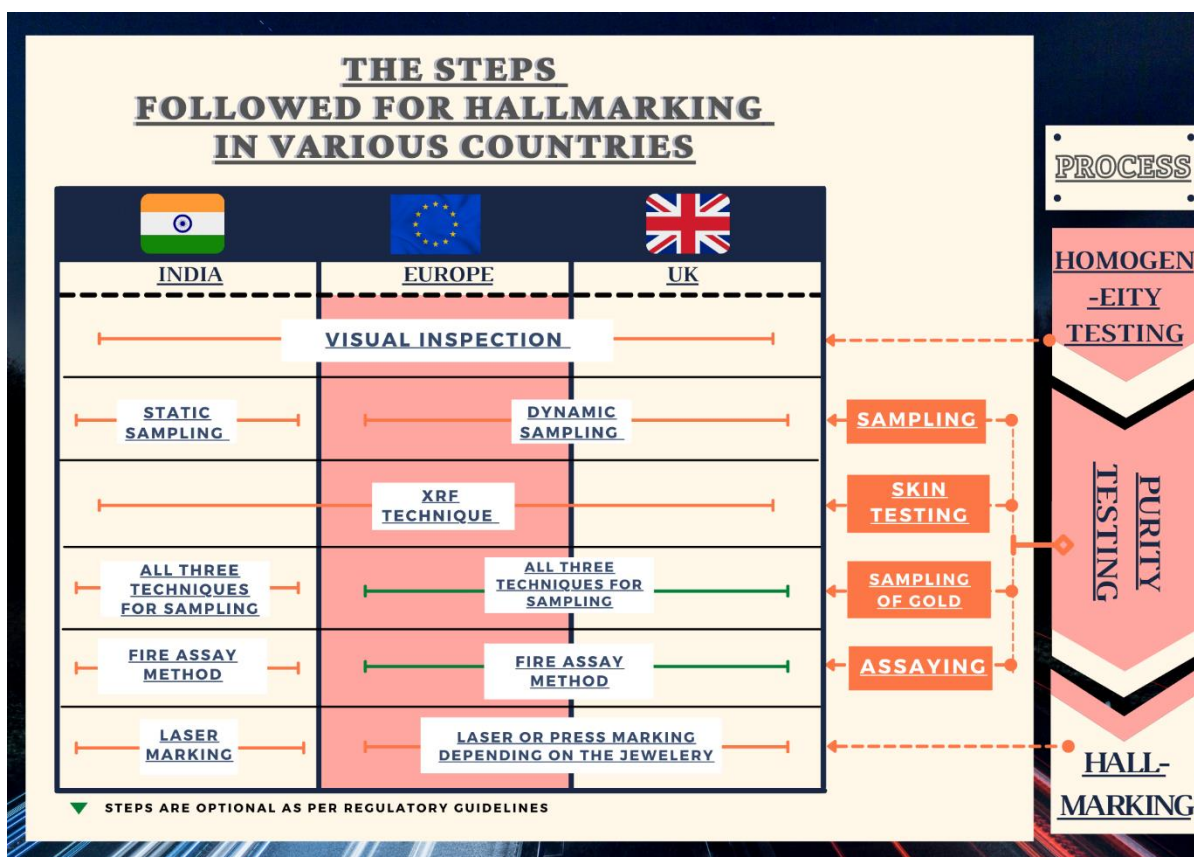
The BIS roadmap of making Hallmarking mandatory across the country will also hit a roadblock as the Assaying Centres would not be able to operate in an effective manner due to the NGT Order.

INTERNATIONAL PRACTICES

Gold is a global commodity and various countries across the world are having their hallmarking schemes in one way or other. The Vienna Convention provides Common Control Mark (CCM), attesting to the material's fineness which is recognized in more than 21 countries. Some of the major consumers of gold like UK, France, Spain, USA have their hallmarking scheme based on XRF and/or Fire Assay Method.

In the United Kingdom (UK), the hallmark is placed after testing by X-ray fluorescence spectroscopy which is a Non-Destructive method and fire assay method is used in case of doubt in purity. Similarly, all gold jewellery sold in France is tested for metal purity and marked with an eagle's head, which has been the official hallmark since 1838. Spain follows a dual system of Assay Office hallmarking and licensed manufacturers marking and Hallmarking is a compulsory state requirement.

The comparative chart of hallmarking schemes in various countries of world is placed as Exhibit 5 given below



The details of Hallmarking Process in various countries are given in **Appendix 1**.

Hallmarking of precious metals is done in various parts of world however the hallmarking scheme followed in India is different from other parts of the world mainly due to the difference in the method of manufacture of jewellery. In European and US Market, most of their Jewellery are casted Jewellery and thus the purity is consistent in the entire jewellery. Thus, non-polluting test methods like XRF are enough to ascertain purity. The polluting methods like Fire Assay and rarely required for certain types of jewellers. Moreover, in many countries, the Assaying Centres are very few in number and hence are easy to regulate.

In India most of the jewellery is hand crafted and most of the times different parts of jewellery are made by different artisans and then soldered together. Thus, there are chances of difference in gold purity in different parts of jewellery. The Gold percentage of a single piece of jewellery can differ in various segments. In such conditions, the non-polluting XRF method may not be enough to ascertain purity as it would provide the purity at a single location. The Fire assay test becomes an essential requirement to ascertain purity. Moreover, India has more than 950 Assaying and Hallmarking Centres which is tough to regulate in comparison to other European Countries.

APPROACHING BIS:

The recent Hon'ble NGT order 18.11.2019 has created a lot of implementation challenges for BIS and Gold Hallmarking Centres and Jeweller.

On learning the above implementation issues, Mr Venkat, Proprietor of M/s Venkatesh Assaying and Hallmarking Centre, Hyderabad had a meeting with local jewellers and learnt that this order would get complications of getting it hallmarked if the hallmark centres are required to be shifted from city business area to outskirts. Mr Khanna, MD of M/s. Mandovi Jewellers and Mr. Venkat discussed the challenges to be faced by Jewellers and issues related to increased risk involved in transportation and will lead to raise in costs of hallmark the article if the Assaying Centres are shifted to the remote Industrial areas.

Mr Khanna, MD of M/s. Mandovi Jeweller, representative of the local jeweller association and Mr. Venkat have decided to visit Hyderabad Branch Office, BIS seeking guidance from the Head (HYBO) over this issue.

During discussion, Mr S V Rao Head (HYBO) apprised them that “An application (OA) No. 568/2019, James Jose, Managing Director, CGR Hall markers Pvt. Ltd. vs Govt. of India was filed in the Hon'ble NGT highlighting the air pollution caused by acidic fumes in gold hallmarking centres from the process of Gold Assaying and Hallmarking without complying the pollution control norms. Hon'ble NGT vide its order dated 18.11.2019 directed CPCB to “update the existing guidelines in the matter so that environmental norms are met in the process”. There are no existing environmental guidelines prepared by CPCB for Gold Hallmarking Centres.

Mr S V Rao further added that “ultimate aim of the hallmark scheme is to provide jewellery with utmost accuracy and reliability to the customer and all over the world fire assay is being used as the proven method for gold testing as its accuracy is the highest and meeting the compliance to the orders issued by of Govt of India imposed is mandatory”.

Mr Venkat and Mr Khanna affirmed to the statement and further asked “why only the fire assay method is only to be followed? Are there any other methods not necessitating pollution control board clearance?”

Mr. S V Rao, Head HYBO further stated that “Birmingham assay office in UK has hallmarks based on XRF results alone”. Hearing this the eyes of Mr Venkat and Mr Khanna lit up and immediately he put up the question to Mr Rao “Then why this cannot be implemented in India also”. Mr SV Rao understood his anxiety and replied that “the conditions in UK and India are different” like in UK most of the jewellery is casted jewellery and thus composition of jewellery is consistent in entire lot, whereas in India most of the jewellery is handmade and many times in one set, small parts received from different artisans are soldered and made into one jewellery set. Thus, there is lot of variation in the gold percentage even in one article.

Mr S V Rao further added that “ISO has published a standard ‘Jewellery and precious metals — Non-destructive precious metal fineness confirmation by ED-XRF’ in which they have also mentioned methods of testing precious metals using ED XRF. However, the standard mentions a lot of requirements of testing machines, calibration standard, method of testing which needs to be studied before implementing in the context of Indian jewellery.

Seeing the unhappiness on Mr Venkat face, he further added that “BIS has undertaken research to see whether any relation can be established between the results obtained by XRF and that obtained from fire assay for the same sample from the referral labs of BIS. He shared the data with them as given in **Appendix 3**. He also stated that better comparison can be obtained if the sample is melted and rolled into a flat strip and then tested by XRF. He suggested somebody should undertake this study to find out if some strong correlation can be drawn between the XRF values and fireassasy and it could pitch for a strong case of XRF replacing fireassay.

Mr. S V Rao further commented on the issues of challenges to be faced by jewellers, a proposal on the scheme of setting up an offsite centre within Industrial area is in progress. In the offsite centre the work up to sampling of jewellery will be done and then the sample shall be sent for fire assay testing to the main centre. The test results can then be transmitted electronically to the offsite centre, and the jewellery hallmarked in the offsite centre and returned back to jeweller. Setting up of an offsite centre would however require additional investment of about 30-35 lakhs.

Mr. Rao also informed them that study on new methods such as Atomic Absorption spectroscopy, inductively coupled plasma are also coming up for testing gold purity however the cost of these equipment is very high ranging from INR 50-90 lakh.

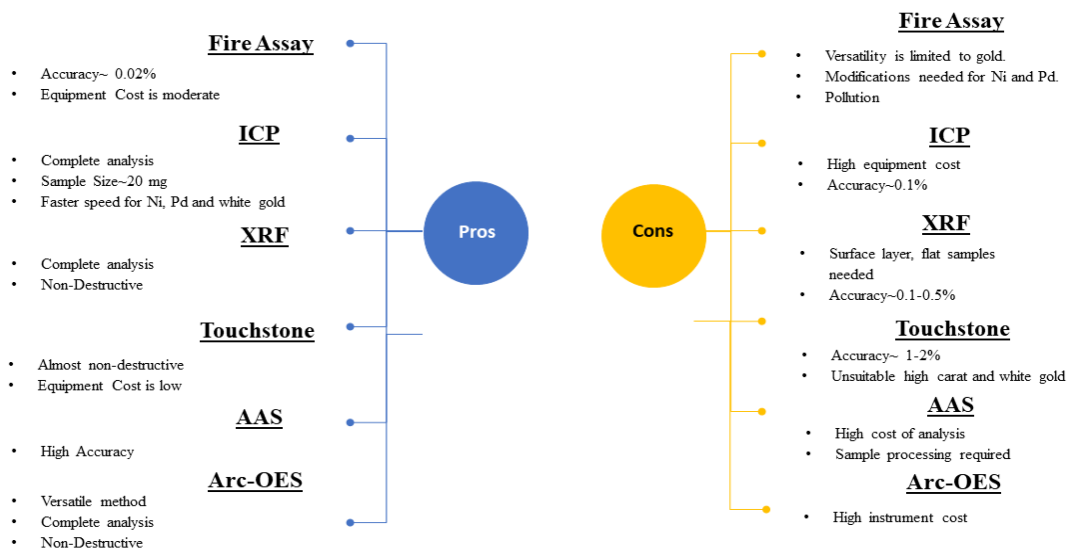
Mr. Venkat and Mr. Khanna thanked Mr. Rao for all the suggestions and left the office thinking about the way forward.

ALTERNATE OPTIONS/WAY FORWARD:

Countries like UK has moved to non-destructive instrumental method for hallmarking finished jewellery items and retained fire assay as a reference for cross checking. The other methods for yellow metal testing are:

- X ray Fluorescence Spectrometry (XRF) -Analysis restricted to surface layers. Accuracy ranges from 0.1 to 0.5 % and moderate cost of analysis.
- Atomic Absorption Spectroscopy (AAS)- High accuracy and higher cost of analysis.
- Inductively coupled Spectroscopy (ICP)- High accuracy and higher cost of analysis.
- Arc Optical emission Spectroscopy (Arc- OES)- Highly versatile method and high instrument cost.

Alternative method recommendations



DISCUSSION QUESTIONS

- *How do you rate BIS hallmarking scheme as compared to schemes followed in other parts of the world.?*
- *Can the methods used internationally be applied in Indian context where in India most of the jewellery is handmade whereas internationally most of the jewellery is casted?*
- *How can the CPCB guidelines be fulfilled with win win situation for both the parties*
- *What options are available with Mr. Venkat for running his centre? Which option is the best as per you?*
- *Do you think any correlation has been drawn between XRF reading and fireassay reading? What could be reasons for the same.*
- *What improvement needs to be done in hallmarking scheme followed in India to make it world class.*

Appendix 1

Vienna Convention

While on this, In the modern world, in an attempt at standardizing the legislation on the inspection of precious metals and to facilitate international trade, in November 1972 a core group of European nations signed the Vienna Convention¹ (Chapter 23) of Law of treaties of United Nations Treaty collection) on the Control of the Fineness and the Hallmarking of Precious Metal Objects. Articles which are assayed and found by the qualifying office of a signatory country which conform to the standard, receive a mark, known as the Common Control Mark (CCM), attesting to the material's fineness. This mark is recognized in all the other contracting states, including: Austria, Cyprus, the Czech Republic, Denmark, Finland, Great Britain, Hungary, Ireland, Israel, Latvia, Lithuania, the Netherlands, Norway, Poland, Portugal, Sweden, Switzerland and Ukraine (1). Other nations monitor the activities of the Convention and may apply for membership.

United Kingdom

The hallmarking act passed in 1973 made hallmarking mandatory in UK. Hallmarks in UK consist of three compulsory and two optional marks (**Appendix 2**) Compulsory marks are the Assay Office mark, the sponsor's or maker's mark and fineness in millesimal number. Optional marks are year mark and CCM. In the United Kingdom (UK), the hallmark is placed after testing by X-ray fluorescence spectroscopy which is a Non-Destructive method and fire assay method is used in case of doubt in purity. Hallmarks are placed on a piece of jewellery by one of permitted four Assay Offices with their own symbol for easy identification. The symbols are a castle, a leopard's head, a rose, or an anchor.

France

France also requires hallmarks on gold jewellery. All gold jewellery that is sold in France is tested for metal purity and marked with an eagle's head, which has been the official hallmark since 1838. This mark indicates that the piece is at least 18k gold, which is the minimum purity that a piece must be in order to be assayed. France also requires a maker's mark be placed on any gold, silver, or platinum jewellery sold in France, which must be a diamond-shaped mark with four equal sides, called a lozenge.

Spain

Spain follows a dual system of Assay Office hallmarking and licensed manufacturers marking. Hallmarking is a compulsory state requirement. Characteristics of the typical mark formation are:

Mark of guarantee: It accredits gold's alloy and can only be put by the Official or Authorised Laboratories of the Autonomous Communities accrediting the official law of the precious metal.

First law: 750 fineness (parts per thousand)

Second law: 585 fineness (parts per thousand)

Mark of identification of origin: It accredits to the manufacturer or importer. This mark must be registered with the Spanish Office of Patents and Marks.

Sponsor mark details: This identifies the person or company manufacturing or importing gold for sale in the country

Fineness: Hallmarking is required for gold articles above 1 g. It is defined in parts per thousand (ppt). Acceptable fineness standards are 375 ppt, 585 ppt, and 750 ppt

Assay Mark: The assay mark has to be one of the following seven assay offices.

V1: Valencia

M1: Madrid

A1: Andalusia

G1: Galicia

C1 and C2: Catalonia

B2: Balearic

USA

In the US, hallmarking is not a legal requirement. Many US jewellery collectors instead look for certain maker's marks for assurance that a piece is of high quality. The problem is that maker's marks aren't regulated, so there's no way of connect a maker's mark to a process that proves a piece is advertised honestly. In fact, in the US, there is no legal requirement to even register a maker's mark; it's simply up to the maker to add their mark as they wish.

In other nations in Europe, other regulations are in place. Some countries require a hallmark, such as Hungary, Sweden, Finland, and Russia. In other nations, like Italy, instead of requiring a hallmark, the nation simply requires that maker's marks be registered, and these are used as a sort of independently monitored hallmark.

The difference between a hallmark and a maker's mark, even in a nation where maker's marks are regulated, is that a hallmark indicates that the piece was physically sent to a third-party office and tested for purity. Even in nations where the maker's mark is registered, it is still based on the honour system, which requires the jeweller to test their own pieces and then advertise them honestly.

Appendix 2

HALLMARKS USED IN UK

Compulsory Marks

The Hallmark comprises three compulsory Marks

- A Sponsor's Mark
- A Fineness Mark
- An Assay Mark

Sponsor's Mark:

The registered Mark of the company that submitted the article for Hallmarking



↓
Metal

Fineness Mark



Expresses precious metal content
(in parts per thousand)

| | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|
| Silver | 800 | 925 | 958 | 999 | | |
| Palladium | 500 | 950 | 999 | 500 | 950 | 999 |
| Platinum | 850 | 900 | 950 | 999 | | |
| Gold | 375 | 585 | 750 | 916 | 990 | 999 |

Assay Office Mark

Exhibits on which Assay Office tested and hallmarked the article



Sheffield



London



Edinburgh



















Birmingham

Appendix 2

HALLMARKS USED IN UK

Optional Marks

You may see some Optional Mark such as The Traditional Fineness Symbol & Date Letter depicting the Year the item was Hallmarked

| Traditional Fineness Symbol | Date Letter | International Convention Marks | Exemption Weights* |
|---|---|---|---|
|  Sterling Silver  Sterling Silver Scotland |  2011  2012 | Silver  Platinum  Gold  Palladium  | 7.78 grams 0.5 grams 1.0 gram 1.0 gram |
|  Britannia Silver  Palladium |  2013  2014 | | |
|  Gold  Platinum |  2015  2016 | | |

***Articles above this weight must be hallmarked**

Appendix 3

On 372 Gold samples, purity was measured through XRF and Fire Assay Methods and the statistical tests were done using T Test.

| Sr No | XRF Reading of Au (ppt) | Fineness in fire assay (ppt) | Sr No | XRF Reading of Au (ppt) | Fineness in fire assay (ppt) | Sr No | XRF Reading of Au (ppt) | Fineness in fire assay (ppt) |
|-------|-------------------------|------------------------------|-------|-------------------------|------------------------------|-------|-------------------------|------------------------------|
| 1 | 926.6 | 916.99 | 125 | 938 | 921.3 | 249 | 927.6 | 919.15 |
| 2 | 922 | 916.67 | 126 | 925.5 | 917.5 | 250 | 960.3 | 919.1 |
| 3 | 923.1 | 914.52 | 127 | 926.5 | 924.5 | 251 | 917.1 | 916.05 |
| 4 | 915.8 | 916.03 | 128 | 930.7 | 924.5 | 252 | 941.8 | 933.6 |
| 5 | 913.5 | 915.08 | 129 | 925.8 | 914.15 | 253 | 924.3 | 916.4 |
| 6 | 914.9 | 914.99 | 130 | 930.7 | 912.1 | 254 | 926.5 | 917.5 |
| 7 | 945.4 | 916.94 | 131 | 934.9 | 915.35 | 255 | 922.8 | 917.3 |
| 8 | 924.5 | 911.72 | 132 | 928.2 | 917.1 | 256 | 933.2 | 915.05 |
| 9 | 917.3 | 916.06 | 133 | 927.4 | 914.05 | 257 | 921.2 | 915.65 |
| 10 | 944.9 | 916.85 | 134 | 915.4 | 915.05 | 258 | 921 | 917.3 |
| 11 | 918 | 916.37 | 135 | 938.7 | 916.75 | 259 | 923.1 | 917.6 |
| 12 | 912 | 913.8 | 136 | 922.9 | 918.45 | 260 | 924.5 | 917.85 |
| 13 | 828.8 | 921.16 | 137 | 944.8 | 916.6 | 261 | 930.8 | 917.25 |
| 14 | 908.2 | 916.93 | 138 | 936.9 | 914.9 | 262 | 941.6 | 919.5 |
| 15 | 916.4 | 915.6 | 139 | 926.3 | 919.5 | 263 | 918.65 | 917.6 |
| 16 | 928 | 927.06 | 140 | 925.4 | 921.7 | 264 | 948.9 | 932.1 |
| 17 | 917.4 | 919.93 | 141 | 931.2 | 922.2 | 265 | 940.3 | 941.05 |
| 18 | 936 | 933.6 | 142 | 919.4 | 917.05 | 266 | 932.6 | 920.35 |
| 19 | 929.8 | 929.71 | 143 | 916.1 | 914.65 | 267 | 919.9 | 915.7 |
| 20 | 937 | 935.22 | 144 | 918.8 | 916.15 | 268 | 919 | 914.35 |
| 21 | 916.8 | 917.29 | 145 | 918.9 | 916.65 | 269 | 928.7 | 916.3 |
| 22 | 934.3 | 931.51 | 146 | 919.8 | 919.55 | 270 | 929.3 | 925.65 |
| 23 | 931.8 | 934.19 | 147 | 943 | 919.9 | 271 | 917.6 | 916.15 |
| 24 | 932.8 | 934.07 | 148 | 937.9 | 919.45 | 272 | 921.8 | 915.35 |
| 25 | 914.7 | 916.72 | 149 | 925.5 | 915.15 | 273 | 926.7 | 917.5 |
| 26 | 935.1 | 933.18 | 150 | 939.6 | 920.2 | 274 | 927.7 | 917.15 |
| 27 | 929.3 | 932.35 | 151 | 923.2 | 914.3 | 275 | 923.6 | 918.7 |
| 28 | 933.7 | 933.32 | 152 | 931.1 | 919.8 | 276 | 919.7 | 917 |
| 29 | 931.6 | 932.42 | 153 | 928.4 | 912.4 | 277 | 930.3 | 918.8 |

| | | | | | | | | |
|----|-------|--------|-----|-------|--------|-----|-------|--------|
| 30 | 923.2 | 924.21 | 154 | 932.9 | 915.75 | 278 | 918.1 | 914.2 |
| 31 | 917.5 | 918.58 | 155 | 922.9 | 919.65 | 279 | 935.1 | 916.2 |
| 32 | 911.3 | 911.29 | 156 | 937.3 | 919.85 | 280 | 917.5 | 916.2 |
| 33 | 925.3 | 916.68 | 157 | 943.4 | 919.8 | 281 | 913.1 | 914 |
| 34 | 915.5 | 920.29 | 158 | 937.5 | 914.35 | 282 | 919.5 | 916.85 |
| 35 | 912.9 | 909.78 | 159 | 937.3 | 918.45 | 283 | 918.5 | 916.95 |
| 36 | 911.7 | 917.54 | 160 | 928.5 | 918.15 | 284 | 921.7 | 917.35 |
| 37 | 771.3 | 752.75 | 161 | 921.4 | 919.65 | 285 | 924.8 | 917.2 |
| 38 | 921.5 | 914.3 | 162 | 920.5 | 920.15 | 286 | 941.6 | 922.3 |
| 39 | 920.3 | 916 | 163 | 919.7 | 914.45 | 287 | 920 | 917.4 |
| 40 | 918.3 | 916.6 | 164 | 921.1 | 915 | 288 | 921 | 915.95 |
| 41 | 924.8 | 914.6 | 165 | 920 | 914.25 | 289 | 960.1 | 949.4 |
| 42 | 926.5 | 915.05 | 166 | 928 | 923 | 290 | 936 | 902.65 |
| 43 | 920.8 | 912.05 | 167 | 935.9 | 915.15 | 291 | 922 | 915.55 |
| 44 | 921.5 | 914.6 | 168 | 932 | 917.4 | 292 | 923.4 | 917.95 |
| 45 | 921.3 | 914.3 | 169 | 925.7 | 915.6 | 293 | 910 | 916.9 |
| 46 | 923 | 914.15 | 170 | 927 | 921.6 | 294 | 918.5 | 916.35 |
| 47 | 922.1 | 916.8 | 171 | 920.2 | 918.05 | 295 | 917.6 | 916.8 |
| 48 | 923.1 | 918.7 | 172 | 921.4 | 919.6 | 296 | 922.1 | 916.35 |
| 49 | 924.2 | 915.95 | 173 | 922 | 921.35 | 297 | 920.6 | 918.85 |
| 50 | 923.5 | 914.3 | 174 | 919.7 | 914 | 298 | 922.8 | 922.7 |
| 51 | 753.1 | 750.1 | 175 | 919.8 | 915.9 | 299 | 925.4 | 923.7 |
| 52 | 923.1 | 914.9 | 176 | 936.7 | 918.85 | 300 | 918.8 | 916.55 |
| 53 | 918.6 | 915.85 | 177 | 927.1 | 918.75 | 301 | 918.5 | 916.05 |
| 54 | 921.2 | 918.5 | 178 | 917.3 | 916.55 | 302 | 920 | 915.1 |
| 55 | 913.3 | 912.9 | 179 | 927.2 | 914.5 | 303 | 922.9 | 917.5 |
| 56 | 915.9 | 914 | 180 | 939.3 | 917.1 | 304 | 921.1 | 912.25 |
| 57 | 918.8 | 916.75 | 181 | 922.3 | 915.8 | 305 | 958.1 | 916.8 |
| 58 | 941.9 | 915.75 | 182 | 922.9 | 918.75 | 306 | 927 | 914.55 |
| 59 | 925.2 | 911.75 | 183 | 940.7 | 918 | 307 | 922.4 | 918 |
| 60 | 918.1 | 916.35 | 184 | 929.3 | 917.6 | 308 | 915.9 | 916.55 |
| 61 | 917 | 911.5 | 185 | 925.6 | 921.8 | 309 | 927.4 | 918.45 |
| 62 | 915.4 | 916.3 | 186 | 921 | 919.6 | 310 | 939.3 | 914.8 |
| 63 | 921.8 | 912.05 | 187 | 917.5 | 915.8 | 311 | 938.3 | 916.25 |
| 64 | 926.2 | 914.95 | 188 | 918.1 | 915.15 | 312 | 931.3 | 918.1 |
| 65 | 925.6 | 917.25 | 189 | 916 | 915.3 | 313 | 947.9 | 918.55 |

| | | | | | | | | |
|-----|--------|--------|-----|-------|--------|-----|--------|--------|
| 66 | 927.6 | 912.7 | 190 | 928.6 | 918.1 | 314 | 920.4 | 908.55 |
| 67 | 922.4 | 921.55 | 191 | 921.2 | 915.1 | 315 | 933.1 | 916 |
| 68 | 927.4 | 918.2 | 192 | 926.8 | 914.9 | 316 | 920.8 | 919.3 |
| 69 | 922.7 | 915.65 | 193 | 932.9 | 919.25 | 317 | 920.5 | 916.9 |
| 70 | 926.4 | 919.45 | 194 | 925.7 | 914.2 | 318 | 931.6 | 917.55 |
| 71 | 941.7 | 915.2 | 195 | 942.8 | 914.95 | 319 | 923.35 | 914.75 |
| 72 | 928.5 | 919.05 | 196 | 928.6 | 914.55 | 320 | 920.2 | 917.1 |
| 73 | 940.3 | 910.1 | 197 | 927.3 | 924.95 | 321 | 921.9 | 914.75 |
| 74 | 943 | 929.4 | 198 | 920.3 | 919 | 322 | 918.5 | 917.65 |
| 75 | 927.3 | 917.2 | 199 | 930.2 | 931.8 | 323 | 935.8 | 917.55 |
| 76 | 923.9 | 918.5 | 200 | 917.5 | 914.7 | 324 | 906.6 | 916.55 |
| 77 | 929.9 | 917.05 | 201 | 914.5 | 912 | 325 | 922.6 | 918.35 |
| 78 | 930.6 | 917.05 | 202 | 919.3 | 916.9 | 326 | 916.5 | 916.55 |
| 79 | 800.6 | 798.15 | 203 | 927.4 | 914.15 | 327 | 929.6 | 917.1 |
| 80 | 928 | 912.95 | 204 | 911.8 | 913.15 | 328 | 920.9 | 917.15 |
| 81 | 918.5 | 916.2 | 205 | 923.5 | 912.55 | 329 | 954.3 | 919.25 |
| 82 | 934.8 | 914.65 | 206 | 919.3 | 913.7 | 330 | 929.5 | 914.8 |
| 83 | 916.4 | 912.15 | 207 | 922.3 | 913.75 | 331 | 919.4 | 915.55 |
| 84 | 765.7 | 750.9 | 208 | 925.6 | 912.85 | 332 | 929.8 | 915.85 |
| 85 | 925.2 | 918.8 | 209 | 917.2 | 914.1 | 333 | 927 | 904.5 |
| 86 | 921.1 | 914.85 | 210 | 920.9 | 915.95 | 334 | 918.35 | 916.55 |
| 87 | 921.9 | 915.35 | 211 | 925.6 | 916.4 | 335 | 920.6 | 918.85 |
| 88 | 916.5 | 915.2 | 212 | 916.5 | 918.5 | 336 | 917.3 | 916.3 |
| 89 | 917.1 | 915.65 | 213 | 945.9 | 916.1 | 337 | 927.4 | 918 |
| 90 | 934.3 | 916.35 | 214 | 928.2 | 917.25 | 338 | 963 | 918.6 |
| 91 | 917.2 | 916.25 | 215 | 932.2 | 917.05 | 339 | 919 | 916.7 |
| 92 | 919.2 | 917.15 | 216 | 945.3 | 917.6 | 340 | 918 | 916.3 |
| 93 | 915.2 | 914.82 | 217 | 928.9 | 918.4 | 341 | 946.9 | 917.5 |
| 94 | 919.91 | 914.8 | 218 | 919.7 | 916.25 | 342 | 922.8 | 917.9 |
| 95 | 929.4 | 916.5 | 219 | 917.9 | 917.05 | 343 | 932.8 | 916.75 |
| 96 | 921.5 | 916.5 | 220 | 919.3 | 916.55 | 344 | 927.6 | 920.9 |
| 97 | 929.4 | 916.55 | 221 | 931 | 915 | 345 | 928.6 | 921.45 |
| 98 | 920.3 | 917 | 222 | 919.4 | 917.2 | 346 | 942 | 921.1 |
| 99 | 922.2 | 917.15 | 223 | 949 | 914.35 | 347 | 936.3 | 920.9 |
| 100 | 923.9 | 918.15 | 224 | 931.3 | 918.8 | 348 | 925.2 | 918.35 |
| 101 | 918.8 | 915.7 | 225 | 925.2 | 916 | 349 | 924.4 | 918 |

| | | | | | | | | |
|-----|-------|--------|-----|--------|--------|-----|-------|--------|
| 102 | 923.2 | 915.7 | 226 | 928.3 | 917.7 | 350 | 925.9 | 917.05 |
| 103 | 932.2 | 914.15 | 227 | 934.2 | 918.2 | 351 | 918.9 | 917.65 |
| 104 | 920.1 | 917.5 | 228 | 921.3 | 917.6 | 352 | 922.9 | 917.2 |
| 105 | 913.4 | 914 | 229 | 918.5 | 915.75 | 353 | 919.6 | 917.6 |
| 106 | 918.6 | 918.5 | 230 | 917.4 | 915.4 | 354 | 935.2 | 910 |
| 107 | 925.6 | 923 | 231 | 920.4 | 915.35 | 355 | 917.6 | 915.55 |
| 108 | 932.3 | 916.8 | 232 | 921.2 | 915.8 | 356 | 949.7 | 916.9 |
| 109 | 941.7 | 912.7 | 233 | 915.5 | 914.6 | 357 | 921.2 | 917.85 |
| 110 | 941.3 | 922.75 | 234 | 930 | 917.2 | 358 | 918.4 | 916.3 |
| 111 | 932.2 | 916.8 | 235 | 938 | 916.85 | 359 | 925.5 | 917.4 |
| 112 | 918.8 | 917.6 | 236 | 932.4 | 916.6 | 360 | 921.6 | 915.5 |
| 113 | 967.7 | 916.45 | 237 | 938.5 | 915.6 | 361 | 924.1 | 915.55 |
| 114 | 954.1 | 931.1 | 238 | 927.1 | 917.45 | 362 | 931.3 | 914.95 |
| 115 | 943.2 | 925.9 | 239 | 923.45 | 924.3 | 363 | 917.4 | 915.55 |
| 116 | 917.6 | 916.7 | 240 | 919.15 | 923 | 364 | 916.4 | 917.1 |
| 117 | 927.2 | 916.75 | 241 | 917.6 | 917.15 | 365 | 929.7 | 915.55 |
| 118 | 918.3 | 914.9 | 242 | 918.5 | 917.05 | 366 | 921.7 | 916.45 |
| 119 | 925 | 914.25 | 243 | 919.6 | 915 | 367 | 930.7 | 915.3 |
| 120 | 923.6 | 915.9 | 244 | 925.8 | 918.55 | 368 | 930.1 | 915.4 |
| 121 | 942.7 | 916.45 | 245 | 920.8 | 916.15 | 369 | 924.8 | 913.5 |
| 122 | 930.7 | 917.35 | 246 | 919.1 | 917.35 | 370 | 923.3 | 918.1 |
| 123 | 935.3 | 918.1 | 247 | 914.6 | 914.35 | 371 | 917.4 | 916.65 |
| 124 | 932.3 | 915.85 | 248 | 922.5 | 919.1 | 372 | 960.5 | 922.95 |

Statistical Analysis

Following Parameters needs to be determined to do Statistical Analysis:

- Mean
- Variance
- Observations
- Pearson Correlation
- Hypothesized Mean Difference
- Df
- T Stat
- $P(T \leq t)$ two-tail
- t Critical two-tail

A paired sample T-test was adopted to compare XRF and fire assay methods for gold testing. The T-test was conducted between the means obtained from the XRF analysis and the fire assay method using a significance level of 0.05, which symbolizes a 5 % risk of concluding the existence of a difference when there is no real difference. The null hypothesis gets rejected if the measured p-value is lower than the significance level, inferring that the difference between the population means is statistically significant. The table shows that the average for the XRF analysis was 924.260645, whereas 915.900322 for the fire assay method. Subsequently, with 371 as the degree of freedom, the p-value was estimated as 4.41570E-42, while the t stat stood at 15.487376930. Thus, the data illustrates that the magnitude of the t-value is higher than the critical value (calculated from the t table) and lies in the rejection region. Furthermore, the computed p-value is considerably lower than the significance level of 0.05; therefore, the two methods indicate a significant difference in usability and cannot be used interchangeably.

| <u>Paired T Test</u> | | |
|--|--------------------|--------------------|
| | 771.3 | 752.75 |
| <u>Mean</u> | 915.825533 | 907.0947208 |
| <u>Variance</u> | 1757.266508 | 1785.221442 |
| <u>Observations</u> | 394 | 394 |
| <u>Pearson Correlation</u> | 0.952887891 | |
| <u>Hypothesized Mean Difference</u> | 0 | |
| <u>df</u> | 393 | |
| <u>t Stat</u> | 13.41051891 | |
| <u>P(T<=t) two-tail</u> | 4.98832E-34 | |
| <u>t Critical two-tail</u> | 1.966018615 | |

