

An Investigation into Nickel Release from Circulation Coins and Coin Production Influences

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Alex Collier (1707158)

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Executive Summary

This report contains a research proposal of the nickel release testing of coins and the influences the coin manufacturing process has. This is to be carried out using BS EN 1811:2011. This is a test method for release of nickel from all post assemblies which are inserted into pierced parts of the human body and articles intended to come into direct and prolonged contact with the skin. Coins are not specifically covered within the standard and prolonged contact is not defined.

The acceptable levels set in the standard are for articles intended to come in direct and prolonged contact with the skin and is set at $0.5\mu\text{g}/\text{cm}^2/\text{week}$.

Nickel release must be measured due to the prevalence of nickel allergic contact dermatitis.

Circulated and uncirculated nickel plated steel blanks and cupro-nickel coins were tested to compare the nickel released by each type of coin. The nickel released by each individual coin was measured.

These results are to be compared to results of a trial in which plating current, annealing temperature and striking force have been amended during the manufacturing process, to produce a quality, in specification coin, but with lower nickel release.

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1.0 Introduction and Literature Review

Many efforts have been made to determine nickel release from coins. Many of these experiments were based on the homogenous coins, containing nickel as an alloy (Cu/ Ni, nickel brass etc.), such as in Euro coins. Since these studies, there has since been a global shift to electroplated coins to save costs (Julander et al, 2013).

Prior to 2012, the UK 5 pence and 10 pence were 75/25 Cu/Ni (cupro-nickel), since 2010, the manufacturing has been carried out using nickel plated mild steel. This has resulted in the surface of the coin becoming 100% nickel.

Nickel is a known sensitizer and regular contact is known to cause skin problems to millions of people worldwide (Spiewak et al, 2007). There is legislation in place designed to protect consumers from nickel exposure when in prolonged, direct contact with the skin, although, this legislation is not specific to coins (Lidén, 2012).

The proposal for this research is to investigate whether the coin manufacturing processes can be optimised, to decrease the amount of nickel released. The samples will be compared against standard production circulated and uncirculated nickel plated and Cu/Ni coins.

1.1 Coin manufacturing processes

1.1.1 Electroplating

Electroplating is an electrolytic process for depositing a layer of metal upon a substrate, to enhance the appearance or properties of a component (Rose, 2014). Electrodeposition occurs when the article to be electroplated is immersed in a solution usually referred to as electrolyte and connected to a negative lead of low current D.C supply, thus becoming a cathode. To complete the electrical circuit, anodes are immersed in the electrolyte and connected to a positive lead. The potential applied between anode and cathode is the driving force for the transfer of charge across the metal solution interface (Canning, 1978).

The Royal Mint offers a range of coatings, these are nickel, copper and brass. Nickel and copper are 'pure' deposits, where the electroplated material is above 99% pure.

It is known that altering the current used in the electroplating process, will affect the throwing power. The throwing power can be attributed to uniformity of the plated deposit (Lowenheim, 1974). It is believed that the main mechanism of nickel release from coins is pitting corrosion (Parcayo-Calderon et al, 2016), although, it is unknown whether the uniformity of the deposit will have an impact on nickel ion release.

1.1.2 Annealing

The purpose of the annealing process is to remove prior cold work. This is carried out using a belt furnace with temperatures often exceeding 950°C, with a holding time of up to thirty-five minutes. This process is necessary to enable the forming of blanks to coins during the striking operation, minimising tooling failure. The process is completed under a protective/inert atmosphere to reduce oxidation.

During annealing, the grains of the material grow. It is not known whether the grain size of the coin will have an effect on nickel release. This growth can be seen in the cross sections in Figure 1.



Figure 1 - As rolled and as annealed microstructure of mild steel blank

1.1.3 Striking

The striking operation converts the coinage blanks into coins. It achieves this by firstly feeding the blanks from a hopper above the coining press, down into the feed mechanism, which in turn by the use of a rotating dial plate locates the blank in the striking position. There are three tool in the striking press, the upper die, the lower die and the collar die. The lower die rises, lifting the coin blank into the collar die, the lower die continues to rise until

contact is made between the upper die and the coinage blank. A striking force of up to 50 tonnes was then employed to 'coin' the blank. The coin produced, now has the design formed into its obverse and reverse sides (heads & tails), and the edge form denoted by the collar (plain, milled, etc). Each coining press at the Royal Mint is able to produce coins at a rate of up to 850 coins per minute.

With increasing striking force, deformation of the coin is increased. It is unknown whether increased deformation has an effect on nickel release.

1.2 Nickel

Nickel is a transition group metal that is silvery-white in colour and lustrous in appearance. On Earth, nickel is the fifth most abundant element, found mainly in the Earth's core, but also in soil, water and air (British Geological Survey, 2008).

This metal has numerous properties, including price, colour and corrosion resistance that make it favourable for a wide range of applications. It is also highly compatible with several other metals over a large composition range, owing to free-state electrons and face centre cubic (FCC) structure.

Nickel is used mostly as an alloying addition in stainless steels or non-ferrous materials. Other uses for nickel include electroplating, high alloy steels and battery production. A break-down of nickel use can be seen in Figure 1.

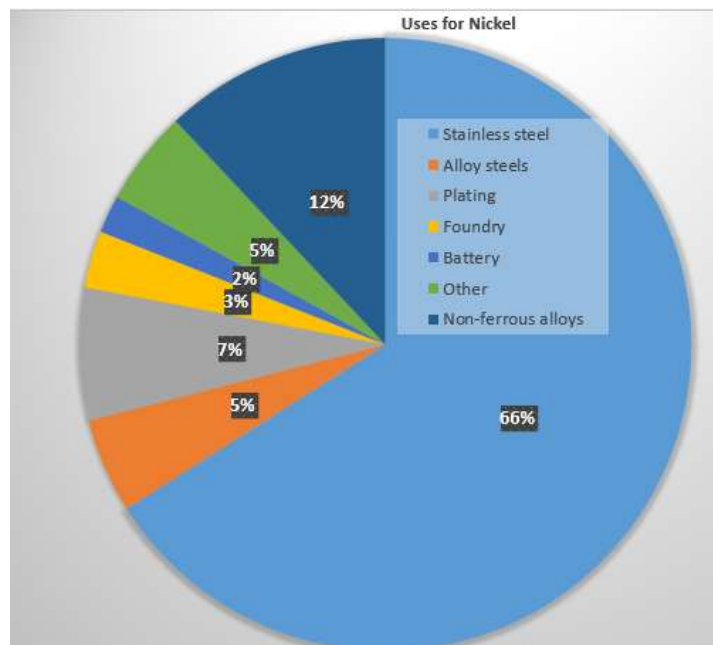


Figure 2 - Use of nickel by % (Rose and Whittingham (2014))

1.3 Nickel use in coins

Circulation coins globally were traditionally manufactured using precious metals such as gold and silver, thus having intrinsic value equivalent of their face value (Searle et al, 2015).

However, fluctuations in metal prices led to the creation of fiat money, a system that uses inexpensive metal tokens assigned a value by the governing body of each region.

Silver coloured homogenous alloys such as Cu/ Ni have replaced silver coins in circulation.

Traditionally, gold coins have been employed to denote higher value coinage, these are now manufactured using alloys such as nickel brass.

These homogeneous alloys however are becoming increasingly expensive (The Royal Mint, 2020). Since the individual metals used to produce the alloys are sourced and purchased at current market rates, they are also subject to the availability and volatility of the commodities market such as the London Metal Exchange (L.M.E.).

One solution to this issue has been to use a less expensive base metal, such as mild steel and to electroplate this with a higher value pure metal or an alloy plate such as nickel, copper and brass (Daniels & VanHoose, 2003).

According to Hamann et al (2013), approximately 60% of all circulation coinage is nickel containing.

1.4 Effects of nickel on health

Although nickel has many advantageous properties, it also has a negative impact on health when it is used for applications, intended for direct and prolonged contact with the human body. Nickel has a strong sensitising potential, causing a varying range of skin problems. All nickel compounds (oxides, sulphides, etc.), other than metallic nickel are known carcinogens (Silverberg et al, 2020)

Nickel sensitisation is well-known to produce allergic contact dermatitis (ACD) in certain individuals, and EU directives are in force to regulate nickel containing products which produce significant nickel release (Yoshihisa and Shimizu, 2012).

ACD reactions vary on an individual basis, with normal symptoms causing the skin to become itchy, blistered and inflamed. The reaction usually occurs within a few hours of exposure to an irritant or allergen. The allergy remains for life once developed.

The metallic nickel is not the cause of the ACD reaction, rather the salts that form as a result of a reaction with a suitable electrolyte (sweat) (Spiwak et al, 2007). It is claimed by Liden (2008), that the handling of coinage is responsible for many cases of ACD.

Nickel allergy is the most frequent contact allergy in the industrialised parts of the world. ACD affects up to 15% of women, with a much lower percentage of men affected. Liden (2000)(2008) and Julander et al (2013) claim this is of public health concern.

1.5 Nickel release regulation

Between the years 2000 and 2004, there was enforcement of the EU Nickel Directive (94/27/EC, 1994), ensuring nickel released from products is less than $0.5\text{mg}/\text{cm}^2$. This was revised in the year 2004, amending the legislation to account for post assembly release and rate of release ($500\text{ }\mu\text{g}/\text{g}$ and $0.5\text{ }\mu\text{g}/\text{cm}^2/\text{week}$ respectively). Piercing metal assemblies were also part of the amendment, stating that rate of release should be no more than $0.2\text{ }\mu\text{g}/\text{cm}^2/\text{week}$ (Nickel Institute, 2017).

A study was carried out on the effectiveness of this legislation by Ahlström (2016), Results showed that there was a preventative effective of the legislation, with decreased incidence in the level of ACD in some EU countries.

Since 2009, the nickel directive has be a part of REACH Regulation Annex XVII. The regulation is for consumer items that contain nickel, and are intended for direct and prolonged contact with the skin. Some products covered include sunglasses, watches, zips, ear and body piercing post assemblies and other jewellery (Intertek, 2011).

It is difficult to apply this test method to coins, as coins are rarely in prolonged and direct contact with the skin.

This reference test for this regulation is BS EN 1811.

1.6 Testing for nickel

As nickel allergies have become more prevalent in society, there has been specific interest in advancing technology to help determine allergens. Tests have also been developed to ascertain whether certain allergen containing products are safe for public use.

1.6.1 BS EN 1811:2011 – Sweat Test Method

The sweat test utilized for determining nickel release from nickel containing products is the BS EN 1811:2011. The test includes leaving a sample in an artificial sweat solution for seven days at 30°C , the sample is then removed and the nickel ions remaining in solution is measured.

Amongst academics, there is some debate as to whether this sort of testing can give accurate results. The main concern seems be centred on the artificial sweat solution used. Stefaniak and Harvey's (2006) argument that suggests the sweat solutions are not

characteristic of human sweat, as a number of factors such as, diet, sex, age and even level of hydration will have an effect on corrosivity.

In 2015, an amendment was published to clarify the compliance criteria for nickel release. The new criteria removed ambiguity around previous 'no decision' range. This range was previously introduced as a measure of uncertainty. This caused some organisations to interpret the standard how they decided (Redshaw, 2015). The revision of the standard now gives a 'pass/ fail' criteria.

Both the new and old criteria can be seen in Table 1.

Post assemblies and body piercings			Other components in direct and prolonged contact with the skin			
Result (µg/cm ² /week)	Under 0.11	0.11 to 0.35	Over 0.35	Under 0.28	0.28 to 0.88	Over 0.88
Old Criteria	Pass	No Decision	Fail	Pass	No Decision	Fail
New Criteria	Pass		Fail	Pass		Fail

Table 1 - Table illustrating the revision of the standard

1.6.2 Patch Test

The patch test is the most commonly used test to identify allergens. The test is carried out by introducing the allergen to adhesive tape, this tape is then contacted with a part of the human body (usually forearm or back) for up to two days (dependent on allergen). The allergen doped adhesive is then removed from the skin, with inflammation measured and graded by severity for a maximum of four days later.

According to Jøhnke et al (2004), this test could be considered subjective, as it is often difficult to distinguish between skin irritation, sensitivity and allergic reactions, especially when using nickel sulphate as an allergen.

1.6.3 Dimethylglyoxime test

Another commercially available test is dimethylglyoxime (DMG) test. This test uses colourimetric methods for screening excessive nickel release from metallic items. The test is

carried out by exposing a cotton bud to DMG solution, the cotton bud is then contacted against a metallic surface for thirty seconds. If the cotton bud changes colour (pink), the nickel release of the product/ item being tested is $> 0.5 \mu\text{g}/\text{cm}^2/\text{week}$ (Ahlström et al, 2019).

Liden and Norberg (2005) state there is some disagreement over the detection levels of this test, there has also been instances of false-positives and false-negative test results. Owing to this, the DMG test method should only be carried out for screening purposes, although, due to it's speed, and non-destructive method, it will continue being used as method for determining nickel release.



Figure 3 - Positive DMG test reaction as indicated by colour change

1.7 Previous experiments to determine nickel release from coins

As stated at the start of the introduction, there have been many attempts to determine nickel release from coins, many of them using BS EN 1811:2011.

A highly cited paper by Nestle et al (2002), found that nickel released from both the one and two Euro coins, exceeded the EU nickel directive by a factor between 240 and 340. It is hypothesised in the paper that the high value of nickel release can be attributed to the difference in electrode potential between the inner and outer parts of the coins. When introduced to a suitable electrolyte (such as sweat), a tiny current is produced between the two parts of the coin, this allows the flow of nickel ions from the coin. Nestle et al (2002) also make reference to the meaning of 'prolonged' as used in the standard, as to whether this level of release would be acceptable or not. The composition of these coins can be seen in Table 2.

Denomination	1 Euro inner	1 Euro outer	2 Euro inner	2 Euro outer
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Material	Cupro-Nickel	Nickel Brass	Nickel Clad Nickel Brass (3 layers)	Cupro-Nickel
Composition	75%Cu/ 25%Ni	75%Cu/ 20%Zn/ 5% Ni	75%Cu/ 20%Zn/ 5% Ni - 100%Ni - 75%Cu/ 20%Zn/ 5% Ni	75%Cu/ 25%Ni

Table 2 - Composition of Euro coin denominations

A paper by Julander, (2013) tested new nickel plated UK 5p and 10p coins against the older cupro-nickel coins using a variation of the BS EN 1811:2011 test method. Times of two minutes, one hour, twenty four hours and one week were chosen for this variation. They found that the amount of nickel deposited onto skin during the handling of nickel-plated coins for 1hr was $7.5 \mu\text{g}/\text{cm}^2$. This was four times higher than the same test carried out with Cu/Ni coins. The results also appeared to show that circulated Cu/Ni coins release more nickel over a week period than nickel plated coins, but less over shorter time periods.

From this, it was concluded that the one week release test method is not suitable to determine the risk of handling items that come into contact with skin for short, repeated contact.

The author found no previous experiments where coins were manufactured using variables of the coin manufacturing process for the purpose of carrying out nickel release.

2.0 Experimental Methods

2.1 Method and materials

The method to be followed is laid out in BS EN 1811:2011 which is the standard for nickel release for assemblies which are inserted into pierced parts of the body or articles intended to come into prolonged contact with the skin. This test method is most widely recognised, and gives numerical values to the results.

2.1.1 Reagents

Artificial sweat solution:

0.5% Sodium chloride (5g +/- 0.01g)

0.1 % lactic acid (1g +/- 0.01g)

0.1% urea (1g +/- 0.01g)

pH 6.5 +/- 0.05 (adjusted using 1M NaOH and 0.1M NaOH)

Degreasing solution:

5% Decon solution

2.1.2 Procedure

- The coins are degreased in the 5% Decon solution, rinsed in demineralised water, and are then dried
- The coins are placed in individual test vessels with a tight fitting lid and covered with artificial sweat solution equivalent to 1ml/cm² of coin surface area.
- The vessels are then placed into the lab oven for 168 hours at 30°C.
- The solution is then decanted to a 50ml volumetric flask made to and made to volume with nitric acid to achieve a strength of approximately 1% nitric acid.
- The nickel content is then measured using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES).
- A control sample is treated in the same manner but without a coin being present

2.2 Calculation

Nickel release is calculated using the following formula:

$$\text{Nickel Released} = \frac{V * (C1 - C2)}{1000 * a}$$

Where:

V = volume of release solution following dilution

C1 = mean Ni concentration in diluted release solution after 1 week in µg/l

C2 = mean Ni concentration in diluted release solution after 1 week in µg/l

a = surface area of the coin.

Nickel release is then calculated and reported as Ni released in microgram/centimetre squared/week (µg/cm²/week).

2.3 Plan

A GANTT for coin production using was created and can be seen in the Appendix. The tasks for the coin production can be seen below, along with the variation in process parameters.

A stillage is a collection container used within the business to move coins and coin blanks between areas.

Plating

Stillages A & B plated at 800 Amps

Stillages C & D plated @ 1100 Amps

Annealing

Stillages A & D annealed @ 800°C

Stillages B & C annealed @ 900°C.

Striking

Samples from stillage A struck at 15, 25 and 35 tonnes respectively.

Samples from stillages B, C and D struck at 25 tonnes.

Samples from stillage A struck on horizontal Schuler production press.

Once manufactured, a sample from each batch will be analysed for nickel release.

Circulated and uncirculated nickel plated coin and Cu/Ni coins have been subject to testing.

This will provide a baseline to compare results against.

3.0 Results

The purpose of this testing is to look at the possible process influences on the level of nickel released from nickel plated steel coins, when compared with standard circulated and uncirculated nickel plated and Cu/Ni coins. Results of standard circulated nickel plated steel and Cu/Ni coins can be seen in Table 3.

	STD NPS (Uncirculated) µg/cm ² /week	STD NPS (Circulated) µg/cm ² /week	Cu/Ni (Circulated) µg/cm ² /week
Average	28.19	14.22	43.54
Min	2.25	0.39	36.41
Max	112.63	89.72	57.78
Std dev	25.57	20.21	3.31
Number	55	95	88

Table 3 - Nickel release measure from circulated and uncirculated coins

3.1 Observations

When looking at all data available, there appeared to be a correlation between the quantity of nickel released and the quantity of iron released.

There is a significantly higher amount of nickel released from Cu/Ni circulation coins when compared to circulated nickel plated steel coins.

There is also a large difference in nickel release between circulated and uncirculated nickel plated steel coins. This is thought to be attributed to the thin nickel oxide (NiO) layer being removed during the handling of the coin.

To test this hypothesis, a sample of coins were passed through a coin validation machine two hundred times, then tested using the same method outlined throughout this report. This mechanical force would remove the NiO layer, potentially resulting in lower nickel release when tested. The result of this trial can be seen in Table 4.

	NPS (200*Validation) $\mu\text{g}/\text{cm}^2/\text{week}$
Average	17.45
Min	0.46
Max	85.32
Std dev	18.16
Number	169

Table 4 - Un-circulated coin passed through validation 200x

The nickel released for all coins is much greater than the acceptable levels set out in the standard; however the standard does not cover coinage specifically and does not define 'prolonged contact'. Skin contact with coins in normal use is normally for a short time however further work is required in this area to confirm this.

When analysing data from the proposed trial coins, all of the above observations will need to be considered. The method of passing sample blanks through the validation machine two hundred times is a 'standard' wear test used at The Royal Mint. This technique will need to be verified as representative of circulating coin wear before testing of trial pieces .

4.0 Evaluation

This type of study has not been evidenced in any literature that the author could find. Carrying out this study will help to understand whether the coin manufacturing process can be altered to reduce nickel release from coins. If successful, these methods could be implemented across other sectors, decreasing nickel released from electroplated nickel products.

As mentioned during the literature review, all test methods used to test nickel release have disadvantages. The method to be used in this study (BS EN 1811:2011) is the only standard available for nickel release, but is not fully compatible for testing nickel release in coins, as coins are not intended for prolonged contact with the human body. In this study it can be used as a useful guide and reference.

For this reason, the results should not be compared to the EU Nickel Directive, but a new standard should be created, taking into account the fleeting nature of coins transactions, along with the results of the trials carried out at The Royal Mint for the purpose of this study.

If no new standard can be considered, a new test method should be developed. The test method should be representative of the way in which coins are handled by consumers. This point is also suggested by other academic papers. Julander (2013) say that the current EU regulation on nickel should be broadened to cover items that come into brief and repeated skin contact, for example coins, tools, and handles, and not only jewellery and other personal items that come into prolonged skin contact.

There may be no appetite to do either of the above due to a recent reduction in coin transactions. Cregan, (2021) States that within the United Kingdom, cash transaction dropped 5% in the retail sector, from 2019 – 2020, although, this may be attributed to the Coronavirus pandemic.

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Appendix

