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# Research Integrity in Corrosion Research

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# RESEARCH INTEGRITY IN CORROSION RESEARCH


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**SUMMARY:** Research Integrity is becoming increasingly important throughout the scientific community. Issues covered by this all-encompassing term can include good data management and security, use of appropriate research methodology, analysis of data based on sound theoretical foundations and correct use of statistics. Ethical issues such as publication authorship, intellectual property rights, conflict of interest and research misconduct including plagiarism, fabrication and falsification of data are also covered.

One of the most significant types of research misconduct is that of scientific fraud. Many well-publicised cases have been reported over the years, most notably in the bioscience, and health/life science fields. Several historical examples are presented which illustrate the nature of such transgressions. A variety of causes have been identified, the misconduct most often being uncovered at a later stage after the findings have been disseminated. Surprisingly much of the research work conducted in some of these areas has proven difficult to replicate resulting in demands for a re-evaluation of all original data leading to the call for open access to all data (Open Science). Although few cases have been reported in the corrosion science area, it has not proven entirely immune from this problem. Some examples reported in the open literature in corrosion science and engineering are presented which illustrate that it is not immune to research misconduct.

As scientists and engineers it behooves us to recognize that rigorous standards of ethical behaviour are always required in the conduct of research. However many of the pressures that corrosion researchers face are similar to those of other scientists, particularly research funding and career advancement. Sometimes this can compromise ethics concerning research in the field with damaging consequences to both the individual involved and the institution's reputations. Sound experimental design with evidence of repeatability of results, high quality journal paper peer-review and editorial processes and verification practices and the need to carefully balance research/scientific needs versus those of industry and commercial enterprises are some of the most important issues of concern.



**Keywords:** Research Integrity, Scientific Misconduct, Corrosion Research


## 1. INTRODUCTION

### 1.1 Description of Research Integrity

Just as Quality Assurance rose to prominence in the manufacturing and service industries at the end of the 20$^{th}$ century, the concept of Research Integrity is becoming increasingly important in 21$^{st}$ century scientific research. But what exactly is Research Integrity? In fact there is no commonly accepted definition worldwide and neither is there for the associated issues of research misconduct, conflict of interest or other key terms that describe unacceptable research practices. Generally research integrity encompasses a range of issues dealing with both the performance of the research activity itself and the dissemination or reporting of the results and their interpretation. In principle scientific research should always be designed and conducted in accordance with ethical principles and with appropriate critical review processes to ensure this. Since 2007 four World Conferences on Research Integrity have been held promoting the exchange of information and with the intention of developing ways to promote research integrity and to harmonise efforts to foster responsible research practices.

Such efforts became necessary because research regulations and accepted research practices can often vary significantly from country to country and even among professional organisations themselves in different fields. For example in Europe one description is found in the *European Code of Conduct for Research Integrity* [1] which identifies eight key principles governing good research practice which are integral to the notion of research integrity. They are:

- objectivity
- reliability in performing research
- impartiality and independence
- duty of care
- openness and accessibility

- honesty in communication
- fairness in providing references and apportioning credit and
- responsibility for the scientists and researchers of the future.

Many European universities have adopted this code and in Ireland there is now a *National Policy Statement on Ensuring Research Integrity* launched in early 2017 [2]. In the UK there is a similar code [3], whereas in Australia [4] and in New Zealand [5] slightly different approaches have been adopted.

One of the most important issues arising from Research Integrity is that of Research Misconduct which describes a range of activities which may compromise research performance or outputs, the three most common types being:

- *Data Fabrication* – defined as the fraudulent creation of results and their recording and/or reporting
- *Data Falsification* – manipulation of research results, equipment, materials or processes, or changing or omitting data or results, such that the research is not accurately represented in the final research output, most often a journal or a conference paper
- *Plagiarism* – the wilful appropriation of other people's ideas, processes, results, or written records without correct attribution. Information or ideas obtained through confidential review of others' research proposals and manuscripts is included in this definition.

Each of these may compromise the integrity of the research. Data fabrication and falsification are probably the most serious offences which may ultimately undermine the development of knowledge itself and can have far reaching consequences outside the research community itself. Although plagiarism (and self-plagiarism) may appear slightly less serious, the corrupting effect on the principle of open communication and sharing of knowledge for wider benefit means that repeated or significant plagiarism is problematic.

Whilst fabrication, falsification, and plagiarism represent the most serious examples of misconduct, there are other types of poor practices which are probably more widespread and therefore potentially more damaging to the reputation of research and the research community's integrity. Such poor practices include:

- *Data-related poor practice* - not preserving primary data, poor data management and/or storage and backup;
- *Publication-related practice* - claiming undeserved authorship, denying authorship to contributors, artificially proliferating publications;
- *Personal behaviours* - inadequate leadership/mentoring of the next generation of researchers and scholars, inappropriate personal behaviour;
- *Financial and other malpractice* - peer review abuse, non-disclosure of a conflict of interest, misrepresenting credentials;
- *Poor research procedures* - harmful, dangerous or unethical research methods

Research integrity is becoming more important in both academic institutional and industrial research programmes, where basic principles such as experimental replication and repeatability have come under threat in recent years. It has even given rise to a new field of academic study and a journal devoted to the topic was launched in 2015 [6].

### 1.2 Aims and Objectives

The aim of this paper is to bring this important issue to the attention of the corrosion research community, including scientists, engineers and technologists, thereby raising awareness of its growing importance and potential future impact. Following a brief historical overview of scientific misconduct cases, mainly in the biological and health/life sciences, some examples of misconduct in corrosion research are presented and discussed. Possible reasons for the lack of research integrity are given, as well as suggestions for the prevention of such problems in future research endeavours.

### 1.3 Historical Examples of Research Misconduct

In principle every scientist should strive to ensure that their research is carried out with the requisite rigour and strictly to the highest ethical standards. Unfortunately in practice this ideal is not always achieved for a variety of reasons, as is illustrated by notable historical examples especially in the bioscience and health/life sciences. Famous examples include the Piltdown Man hoax, Lysenko and his rigid adherence to the Lamarkian view of evolution, Mark Spector and his cell biology results and more recently examples in the field of stem cell research. Even though the majority of these have arisen in the biosciences and health sciences, it is not solely the preserve of these fields and some other cases in the physical sciences are also well-known.

One of the best known cases in the physical sciences was that of "polywater", an example of what the American Chemist Irving Langmuir termed "Pathological Science" [7]. He described behaviour where "people are tricked into false results….by subjective efforts, wishful thinking or threshold interactions". In the case of polywater a Russian scientist Nikolai Fedyakin in 1961 reported water present in glass capillaries with a range of strange properties; an elevated boiling point, depressed freezing point and a much higher viscosity in comparison to normal water. Careful investigations conducted by Boris Derjaguin confirmed these findings, which aroused much interest. However later investigations discovered that the water was contaminated with compounds that gave rise to these unusual properties (as a result of the water's colligative properties) [8].

A more recent case of misconduct in the physical sciences was that of Hendrik Schön a young German physicist who rose to prominence after making a series of astonishing breakthroughs in experiments involving organic-based semiconductor materials. These were later discovered to be fraudulent, but only after he had been awarded a series of prestigious prizes (later to be rescinded) including the 2002 Young Investigator Award of the Materials Research Society [9]

Perhaps the best-known case of pathological science which occurred in a field closely allied to Corrosion Science was the "cold fusion" claims of M Fleischmann and S Pons made in Utah USA. Announced in a tumult of publicity in 1989 they claimed to have produced excess heat along with helium, neutrons and tritium by-products when heavy water ($D_2O$) was electrolysed on the surface of a palladium electrode [10]. Efforts to duplicate their results met with varied success. Finally panels assembled by the US Department of Energy in November 1989 and again in 2004 concluded that there was no convincing evidence for the occurrence of fusion at room temperature. Work has since continued on the topic now known as either: Low-Energy Nuclear Reactions (LENR), Condensed Matter Nuclear Science (CMNS), or CANR (Chemically Assisted Nuclear Reaction) [11].

Other examples of pathological science include the N-rays of Blondlot (1903) and Benveniste's Water Memory or homeopathy report published in Nature in 1988. The above historical examples (amongst others) show a wide range of questionable behaviour, ranging from Langmuir's pathological science to outright fraud and seem to have occurred for a wide variety of reasons [12].

## 2. EXAMPLES OF RESEARCH MISCONDUCT IN CORROSION SCIENCE

Although examples of such misbehaviour in corrosion science are comparatively rare, the authors have identified several cases which are presented in this section. Their impact varied widely. Whilst some were only potentially of minor interest to researchers in their own particular narrow research field, others were of far more widespread concern, with high potential impact and serious implications for population health and wellbeing. By no means a comprehensive list, it does however indicate that the problem of research misconduct is not solely the preserve of the biosciences and social sciences. There may be other cases in the corrosion science realm which remain yet to be revealed.

### 2.1 Alleged Corrosion Research Misconduct Example 1: Galvanic Corrosion in the Water Supply Industry

The first example deals with research conducted on copper-lead pipe galvanic (dissimilar or bimetallic) corrosion in Washington D.C. drinking water that was later questioned by two well-respected corrosion scientists. It is well-known that, depending upon a number of different factors, lead (in old pipe installations) and copper can enter drinking water through corrosion of metal plumbing systems. As a result of drinking water from these pipes health problems from both metals (copper and lead) may arise. They can range from stomach illness to irreversible brain and nervous system damage, with children being especially vulnerable. In 1991 the EPA in the USA published a regulation to control lead and copper release in drinking water known as the Lead and Copper Rule (LCR) [13]. The rule requires water utilities to monitor drinking water at their customer's taps. Accordingly, if the lead concentrations exceed 15 ppb or copper concentrations are above 1.3 ppm in more than 10% of samples, the utility company must then take remedial action to control the corrosion. If the 15 ppb level for lead is exceeded, replacement of the lead service lines (LSL) may have to be undertaken. Copper is the preferred metal for this approach, with partial replacement most often carried out.

Partial replacement of the lead pipe with one made from copper is likely to result in galvanic corrosion as the dissimilar metal pipes are always electrically connected by an earth strap. A further complication arose when the water treatment was changed from one involving chlorination to one using chloramine, whose affect was not as well-documented. This resulted in a "DC water crisis" with almost 15,000 homes having partial LSL replacement between 2004 and 2008 at an estimated cost of over $100 million [14]. This approach was called into question by the US Centers for Disease Control and Prevention (CDC) who issued a report in 2010 stating that "…children living in housing where a lead line was partially replaced after 2003 were more likely to have (elevated blood lead levels) than children living in housing without a lead service line" [15]. In addition "partial lead service line replacement was not effective in decreasing risk for higher blood lead levels", with the risk similar to that for people who never had their lead lines replaced.

Depending upon a number of factors such as water chemistry, water flow rates and the existence of passivated surfaces, most corrosion scientists consider that galvanic corrosion between lead and copper pipes in water systems may occur. For example the BSI Commentary on Corrosion at Bimetallic Contacts and its Alleviation PD 6484:1979 [16] predicts that lead when connected to copper in fresh water will suffer a range of potential corrosion outcomes; from "no additional corrosion or only very slight additional corrosion to slight or moderate additional corrosion which may be tolerable in certain circumstances". The effect is variable though, with bicarbonates, sulfates and silicates mitigating against corrosion, whilst aeration and elevated temperatures will promote it. More recent studies have confirmed the enhancement of lead corrosion by copper, which may explain the elevated blood lead levels mentioned in the CDC Report. Consequently it is normally recommended that when carrying out a partial LSL replacement procedure utilising a copper pipe joined to an existing lead pipe, that an insulating or dielectric spacer (such as a PVC pipe or flange) be inserted between the two metals, which are then usually electrically joined together by an earth strap.

However one study carried out by a team of researchers reported in the peer-reviewed *Journal of the American Water Works Association* (JAWWA) seemed to disagree with this commonly held view [17]. Contrary to expectations, this research concluded that galvanic corrosion was "limited to the immediate vicinity (~5 mm) of the lead-copper connection" (a distinctly localized region) and that, most importantly, "accelerated metal release with this type of galvanic coupling may be minimal". This is a significant finding as it would suggest there was no need to insert a spacer between the dissimilar metal pipes, nor was the lead level in the drinking water likely to increase significantly over time once the new installation was commissioned. In addition, the authors of the article also stated that if the lead and copper pipe were separated by 1 cm to 15 cm and an external wire (such as an earth strap) used to maintain electrical contact, the measured potential of the "entire lead coupon shifts in an anodic direction" and thus "galvanic coupling has likely accelerated lead release by up to ten-fold". This was supported in their paper by measurements of corrosion potential ($E_{corr}$) at different locations over the galvanically connected metal pipe surfaces. Significantly no galvanic current measurements were taken nor were any total lead concentrations in the recirculated water determined by commonly used methods such as AA or ICP.

Corrosion experts were surprised at this finding, as it is often considered that pipe galvanic corrosion is most often limited to a region of about 1.5 times the pipe diameter and increased separation of the bimetallic couple generally reduces galvanic corrosion through the operation of an ohmic resistance or "distance effect" [18]. The highest galvanic corrosion rate is obtained in the absence of any ohmic resistance ($iR$). However, increasing the solution $iR$ by increasing the separation of the anode and cathode elements will reduce the extent of galvanic corrosion. Shortly after publication two well-respected corrosion scientists, Marc Edwards and Gerald Frankel, questioned the findings of the JAWWA study [19]. In a Discussion document (entitled "Effect of Changing Water Quality on Galvanic Coupling") published in the same journal in 2012 [20] Edwards pointed out a number of problems with the original JAWWA paper. In addition to the lack of recognition of decades of perceived corrosion wisdom backed up by literature evidence, and after contacting the original paper's authors for answers, Edwards pointed out a number of other issues with the paper. These included discrepancies between data presented in some of the figures and that discussed in the text, problems with graphics depicted in some of the figures (especially figures 9 and 10) which were performed by a graphic artist with mis-labelled axes. Some data was missing and errors were apparent in data presentation such as combining several separate curves to create a single curve unrepresentative of the actual time-dependent corrosion behaviour. Furthermore, Edwards mentions other concerns such as text being written before completion of experiments, only short term results (< 5 days) being obtained, errors in total lead determination (i.e. failure to ascertain particulate lead) and providing supporting evidence that was not able to be verified. As a consequence of this Edwards asked for the paper to be retracted by the journal.

After corresponding with the journal editors and seeking information from the authors, in addition to using a freedom of information request, Edwards wrote a letter to the journal editor which was published in January 2014 [19]. Published in the same issue was another letter by Gerald Frankel. Both highly respected corrosion scientists expressed severe reservations about the science described in the original JAWWA article which appears to contradict both experience obtained in the field and laboratory studies conducted on galvanic corrosion over many years. Results from the original study which purport to show that use of partial LSL replacement will only have a minimal effect on lead release in potable water (and thus lowered entry into the bloodstream of consumers) could have immense public health significance. In response to these criticisms, the journal editors however did not retract the paper. Instead they published an "Expression of Concern" [21] along with the recommendation that readers refer to a report (public project paper) [22] which summarises information from both the original study and from a separate one performed by Marc Edwards in the same locality.

In his Discussion document Edwards ascribes the errors published in the original paper to Langmuir's "pathological science" where "well-intentioned scientists have been tricked into false results by wishful thinking and other factors". It does seem strange that the three reviewers of the original paper did not detect important issues concerning aspects of the corrosion study which was later called into question by Edwards and Frankel. The reviewers may well not have understood the fundamentals of corrosion science at a sufficient level which highlights one of the essential problems in the reviewing process; namely reviewers must have sufficient knowledge of the area to make valid judgements. Edwards later confirmed flaws in the original study by conducting a carefully controlled investigation which was published in the NACE journal *Corrosion* in 2012 [23]. Contrary to the original paper's results, Edwards et al confirmed that direct coupling of 1.9 cm diameter lead and copper pipes caused a sudden large increase in lead release. In addition increasing lead-copper separation distance through insertion of PVC pipe sections resulted in diminished levels of lead with lower levels occurring with longer PVC lengths. It is also worth noting that Edwards used a more suitable methodology in his study. Rather than relying upon measurements of $E_{corr}$ (which does not give any information on corrosion rates) he determined the corrosion current, the level of total lead in the water using ICP-MS and also conducted a visual inspection of scale build-up. The study was conducted over a much longer time period (4 months), instead of only a few days. The Edwards study confirmed that, as expected, directly connecting lead and copper pipes together will increase the rate of lead release and the use of an insulating material to effect pipe separation will diminish it.

### 2.2 Alleged Corrosion Research Misconduct Example 2: Metallic Corrosion Inhibition

The second example concerns a number of papers published over a period of many years in high-impact corrosion, electrochemical and materials science journals. Curiously, it was one of the other members of the research group who highlighted the problem. He published a series of five papers in 2013 and 2014 [24-28] that raised concerns about data presented in a large number of journal articles (over 40) on inhibition and corrosion studies on a variety of metals published by other members of the group from 2001 until 2011. Apart from one paper which uses the term "Scientific Integrity" in its title, the other four use "Scientific Fraud" as part of their titles which demonstrates his view of the work's authenticity.

The first, published in 2013, entitled "Scientific Fraud in the Digital Age" [24, 39] employed graph digitising software (UN-SCAN-IT) in conjunction with commercial graphing programs (Origin and Sigma Plot) to compare results presented in two PhD student theses with those published ostensibly from the same work in reputable peer-reviewed journals. The journals cited in this review included: *Applied Surface Science*, *Corrosion Science*, *Journal of Applied Electrochemistry*, *Electrochimica Acta* and the open access journal *International Journal of Electrochemical Science*. Comparable figures identified in the two theses which had virtually the same captions in the journal articles often had a very different appearance which is evident by eye. Plots presented in the review paper as evidence of the alleged fraud consisted of Nyquist EIS plots, inhibition efficiency versus concentration plots, potentiodynamic polarisation curves and plots of anodising potentials as a function of time. They appeared different in most but not all cases (e.g. the Tafel polarisation plots looked very similar). Also it should be noted that the scales on the EIS Nyquist plot axes were different in both cases, being in ohm in the thesis and ohm $cm^2$ (or sometimes incorrectly ohm $cm^{-2}$) in the papers. Of most concern was the finding that another thesis from 2007 contained results which served as the basis for three papers. The data showed no sign of any random (or systematic) error and through digital analysis it was claimed that the weight loss, Nyquist EIS and Tafel polarization plots were all adjusted by use of a multiplication or scaling factor. The review stated that "we proved that these results are fabricated and never been experimentally obtained". Furthermore it was also concluded that "the same fabrication technique was used in falsifying the data presented in other articles" (of which 26 were listed).

A similar conclusion was reached in the next article in the series entitled "Scientific Fraud and its Implications on Electrochemical and Corrosion Science Research" [25] in which data from inhibition of low carbon steel was examined. The paper in question "The inhibition of low carbon steel corrosion in hydrochloric acid solutions by succinic acid" was published in *Electrochimica Acta* in 2007 and which has been cited more than 280 times. Weight loss data as a function of time (gravimetric/time graphs) show perfectly straight lines and values at different inhibitor concentrations again seem to have been generated by multiplying by a constant factor. Digitisation of the polarisation (Tafel) curves indicated that they appeared to have been shifted along the potential axis which suggested that the data had simply been manipulated by multiplication by different constants. Further evidence for this manipulation is that the anodic and cathodic Tafel slopes reported are remarkably consistent ($\pm$ 1.5 mV $dec^{-1}$) over an extremely wide range of pH and inhibitor concentrations. EIS Nyquist plots also seemed to have been generated by applying such scaling factors in the real and imaginary axes. In addition, the appearance of an inductive loop was thought by the reviewer to be unusual under such conditions (1.0 M HCl). It was also recommended, that in future publications that the journal editors and reviewers use a similar approach in order to identify any suspicious data that had simply been scaled by such a process. The present authors have noticed some further anomalies in the paper. Figure 13, for example, purports to show the EDX spectra of the steel substrate but, rather than two narrow peaks (K-alpha and K-beta) characteristic of iron an unusually broad single peak occurs between 6 and 8 keV. Similarly the polarisation resistance values, $R_p$, in Table 2 does not reflect the values expected from the quoted Tafel slopes ($b_a$ and $b_c$) and the value of $i_{corr}$ obtained by Tafel analysis.

In the third review paper entitled "Scientific Fraud in Corrosion Science Research: A Review" [26] published in a different journal in 2014, the digitisation approach was again used to investigate the veracity of weight loss and iron dissolution data published in a number of papers by the same authors. Eight cases were presented which were alleged to show evidence of data fabrication. The work was all published in reputable journals with relatively high impact factors. In the first case published in *Corrosion Science* [27] 162 points said to be obtained from steel dissolution in 4.0 M $H_2SO_4$ which all align as completely straight lines are shown. This is surprising as the acid solution was stagnant and such perfect alignment would not be expected. Digitisation analysis seemed to indicate that all the lines with various amounts of a glycine derivative inhibitor were scaled by different multiplication factors. The next example using similar glycine derivative inhibitors was also published in 2010 in the same journal [28]. This time dissolved aluminium was measured in 0.5 M KSCN as a function of time. As before, remarkably consistent linear plots were obtained of dissolved aluminium against time; all 126 points lying exactly on the straight lines, which again appeared to be possibly obtained by a scaling process. Another paper [29] published originally in 2009 in *Corrosion Science* also dealt with the corrosion of aluminium in weakly alkaline solutions inhibited by polyacrylic acids. Once again plots obtained over time (this time representing weight loss) were extraordinarily linear and all described as having "zero percent error". Like the previous examples they also appeared to be directly scaled as were the results in the next two studies examined, which both involved measurements of weight loss corrosion of steels published in 2007 in *Electrochimica Acta* [30] and in *International Journal of Electrochemical Science* in 2008 [31].

Another study on the inhibition of copper corrosion published in the *Journal of Applied Electrochemistry* in 2006 presented remarkably linear weight/time data (all 110 data points lying exactly on one of the 11 lines and appearing to pass directly through the origin) as well as polarisation and impedance data obtained from 25° C up to 65° C [32]. There appears to be virtually perfect alignment with remarkably consistent agreement between results obtained from all three experimental methods (gravimetric and electrochemical) which is presented in a figure showing inhibition efficiency versus logarithm of the inhibitor concentration. It was suggested that this too could have been obtained by a scaling procedure. The final two examples presented in the Review paper were both published in the journal *Materials Chemistry and Physics* in 2001 and 2002 [26]. They present data that was supposedly obtained from aluminium corrosion in different inhibitors and once again present perfectly linear weight loss vs time plots that may have been scaled.

The next paper in the series which was published in the same journal as the Review article (also in 2014) was entitled "Scientific Integrity in the Digital Age: Data Fabrication" [33]. Although it listed 30 articles from 2001 to 2011 which utilised "the same fabrication technique….to fabricate the data presented in other articles" it discussed in some depth with two articles by the same individuals as before. The first published in the *Journal of the Portuguese Electrochemical Society* (*Portugaliae Electrochimica Acta*) investigated "The inhibition of Uniform and Pitting Corrosion Processes of Al Induced by $SCN^-$ anions: Part 1 The Effect of Glycine" [34]. Visual inspection of their weight loss data (obtained through use of ICP-AES) again revealed that all 84 data points were located exactly "on straight lines with zero percent error". It then described this as "experimentally impossible and has never been reported in the literature except for articles published (by) the same authors", citing twelve of their publications. Once more it was claimed that use of a simple multiplication or scaling procedure achieved this experimentally unlikely result. Less evident but just as disconcerting was the author's assertion that the electrochemical cyclic polarisation plots were also fabricated. Through use of the digitizing software it was possible to replicate all the curves by multiplication (or division) by constant factors to scale the current density data and thus obtain an exact match of the published polarisation curves.

A similar analysis was performed on cyclic voltammetry (electrochemical) data reported in *Electrochimica Acta* [35] entitled "On the Role of $NO_2^-$ ions in Passivity Breakdown of Zn in deaerated Neutral Sodium Nitrate Solutions and the Effect of Some Inorganic Inhibitors". A digitisation analysis again seemed to indicate that the data was simply scaled and the reported current peaks although diminished with each successive scan, did not appear to change their position (on the potential axis) possibly due to a change in surface ohmic current contribution.

The final paper in this series by the same author "Scientific Fraud and the Power Structure of Science" was also published in *Research in Chemical Intermediates* in 2014 [36]. Although this paper discusses aluminium corrosion results in a paper published in *Corrosion Science* [29], it also questions the results presented in more than other 40 articles by the same authors, all published in high profile journals. It even includes a link to supplementary material which is available on a YouTube channel [37].

The experimental work mentioned on this critical review was performed as part of a Masters thesis from 2005. It presented weight loss data showing seven perfectly straight lines of weight loss as function of immersion time, with all 96 data points lying exactly on one of the 7 straight lines. Not a single point lies off any of the lines. The use of a scalar (multiplier) to obtain the data is again suggested. Furthermore in this example careful digitization analysis also seems to suggest that polarization curves (Tafel plots) and also Nyquist EIS plots were obtained using a similar multiplier (scaling) approach.

This series of review papers raises serious concerns about the authenticity of the work reported in over 40 peer-reviewed papers, as well as the standard of the editorial and journal review processes. In multiple cases the published weight loss/time and metal dissolution/time the data seems uniformly (and suspiciously) perfect without any outliers. Nor are any error bars apparent in any of the plots which seem to be single value results. It is not clear if replicate samples (even duplicate or triplicates) were ever tested and there is no evidence of any random (or systematic) errors occurring in any of the data reported. As the critical author commented they were "zero error plots" and it is surprising that questions had not been raised earlier, given that the articles went back to 2001. A digitisation analysis appeared to confirm that a simple scaling procedure could have been used to obtain such graphs. Consequently it was suggested that journal editors and/or reviewers use such an approach to ascertain the likely provenance of results presented for review. The use of a similar multiplier or scaling technique to obtain electrochemical data (e.g. Tafel plots and EIS plots) and other results (such as inhibition efficiency/inhibitor concentration plots) is somewhat surprising. It is also more disturbing as this is less obvious upon visual inspection, although corroding electrodes are not usually dimensionally stable and normally their surfaces change from scan to scan.

A response to these claims was published in the same journal also in 2014 [38]. Although it was suggested that it would be the first in a series whose intended aim was to "respond to the Paper Scientific Integrity in the Digital Age- Data

Fabrication" it appears to be the only paper to have been produced thus far, at least according to a check carried out using Google Scholar. This response article is perplexing, as it concentrates largely on the fact that the numerous weight loss/immersion time and comparable metal dissolution concentration/immersion time plots all go through the origin. Several examples of data going through the origin are presented in this paper. None of the plots however presented as supporting evidence in Figures 2-4 are of weight loss/time or metal concentration/time. Instead they are plots of I-V in a CdS thin film (photo-electrochemical), a polarisation resistance plot (which traverses the origin at an overpotential of zero) and an erosion/time plot of a wear experiment. Such plots are not comparable to the weight/dissolution figures presented in the offending papers. However two plots (figures 5 and 6) of weight loss versus time are presented which do appear to show similar behaviour to those in the papers. Derived from studies conducted on inhibition of aluminium corrosion, both reports which emanate from another group in the same country are published in a very low impact journal (IF < 0.5). Another report which also appears to support their contention that weight loss/time plots do indeed traverse the origin was published in a high impact journal, *Corrosion Science* (5 year IF>5). However this journal also published many of the articles questioned in the series of five critical reviews [24-28] previously discussed.

More important though than the question of whether such weight loss/time (and metal dissolution/time) plots do indeed go through the origin, is the failure of the author of the response paper to mention the perfect alignment ("zero error") of his weight loss (gravimetric) corrosion data. Such perfect straight lines of what amounts to thousands of data points over all the papers examined in the critical review series require a very good explanation, which is not provided. The response paper does, however, point out that 18 papers do not contain plots with figures with straight lines going through the origin. Although this assertion may be correct, an inspection of seven of these papers published in *Electrochimica Acta* revealed that they did not contain weight loss data at all. Many of them presented results of pitting corrosion studies for which weight loss/time plots would have been totally inappropriate. The author does not address in his rebuttal nor other issues associated with rescaling of polarisation, EIS, and other data sets, but does note that he has co-authored three papers with the person accusing him of fraud. Many of these papers contain similar deficiencies (e.g. perfectly linear weight loss plots).

Crucially **none** of the papers mentioned in the critical series appear to have been retracted and are still available for use by corrosion science researchers. At least ten of the suspect papers have been cited more than 100 times (Scopus) so that the corrosion community in general appears unaware of these issues.

### 2.3 Alleged Corrosion Research Misconduct Example 3: Author Issues, Plagiarism and Retracted Papers in Corrosion Science

The third corrosion science example involves issues of authorship and plagiarism/self-plagiarism during dissemination of research results. In the first case reported on the web site Retraction Watch, [40] two papers published in 2014 in the *Journal of Dispersion Science and Technology* [41, 42] seem to be both substantially similar to another paper, published in the same journal in the previous year [43]. Both papers were retracted and also appeared to have used data published in a 2013 article from another journal, *Industrial & Engineering Chemistry Research*, "without proper citation." [44]. Like many of the papers mentioned in example 2 above, these publications dealt with corrosion inhibitors, in this case for prevention of mild steel corrosion in hydrochloric acid. The *Industrial & Engineering Chemistry Research* paper shares several authors with the 2013 *Journal of Dispersion Science and Technology* paper.

According to the publishers of the *Journal of Dispersion Science and Technology*, "these actions constitute a breach of warranties made by the authors with respect to originality. We note that we received, peer-reviewed, accepted, and published the article in good faith based on these warranties, and censure this action. The retracted article will remain online to maintain the scholarly record, but it will be digitally watermarked on each page as RETRACTED". A similar notice was also issued for another paper in the same journal [45]. The issue largely centres on self-plagiarism; that is using identical results for more than one publication without acknowledgement of the source of the data and attempting to present this as original material when it clearly is not.

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Several other instances of similar misbehaviour were also found in other retracted papers in the corrosion science area. A paper entitled "Mechanism Responsible for Synergy Between Fretting and Corrosion for Three Biomaterials in Saline Solution" published in the journal *Wear* in 2001 was retracted as the work was "substantially based without the author's permission, on material submitted" for another person's PhD "and that it was submitted for publication without "either their or the third author's knowledge [46]. Consequently the "Editor-in-Chief of *Wear* (and the publisher), who published the article in good faith, now wish to treat this paper as retracted and express their disappointment at the inconvenience caused to" the former PhD student and the article's third author. This appears to be a clear case of plagiarism of another researcher's work. It also implicates another author who did not appear to be aware of the paper before submission which is unacceptable behaviour.

Another retracted paper, was published in *Materials Science and Engineering; A* in 2005 [47]. Entitled "Mechanical Properties and Corrosion resistance of Low-Alloy Steels in Atmospheric Conditions Containing Chloride" the Editor requested that the article be retracted as it "duplicates significant parts of a paper that had already appeared in *Corrosion Science* 47(2005) 1001-1021". It was pointed out that "one of the conditions of submission of a paper for publication is that authors declare explicitly that their work is original and has not appeared in a publication elsewhere". Evidently this was not the case in this instance resulting in a situation where data was not appropriately cited. The retraction statement concluded that "the scientific community takes a very strong view on this matter" and furthermore "apologies are offered to readers of the journal that this was not detected during the submission process". This is not an uncommon practice. Indeed once when serving as technical convenor of a Conference, one of the authors of this paper highlighted such an issue with a submitted conference paper that was substantially the same as another paper albeit with a different title, that had just been published in a reputable journal.

A paper "Structure adhesion and corrosion resistance study of tungsten bisulfide doped with titanium deposited by DC magnetron co-sputtering" published in *Applied Surface Science* [48] was retracted at the request of the Editor-in-Chief "because this paper had been written and submitted to the journal by the corresponding author, without the consent of (some of) the co-authors". According to the retraction notice "one of the conditions of submission of a paper for publication is that all authors have approved the manuscript and have agreed to submission to a journal. Since this condition has been violated, this paper will be retracted". Just as in the previous example some authors had not approved submission of the manuscript before submission to the journal.

The final example involves self-plagiarism in which images taken from other publications were inserted into a paper published recently (2016) in the *Journal of Materials Science: Materials in Medicine* [49]. The retraction note from the journal stated that "following a complaint about the republishing of unreferenced data in several journals including (this journal) the following issues were detected: there are textual similarities and duplication of images in the….paper and in "The effect of electropulsing induced gradient topographic oxide coating of Ti-Al-V alloy strips on the fibroblast adhesion and growth" authored by Xiaoxin Ye, Zion Tse, Guoyi Tang and Guolin Song, and published in *Surface and Coatings Technology*, notably Figures 2 and 3(a) in the latter article appear as Figures 5 and 7 in (this journal) paper without reference to the original publication. In addition, similarities in other Figures (for example, Figures 8 and 9) have been noted with a number of other publications….". Two Materials science journals were named. It was also noted that (the paper) was "hereby retracted at the request of the Editor-in-Chief and with the agreement of the authors".

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## 3. DISCUSSION

In the first example considered there does not appear to be any direct evidence of data fabrication, falsification or plagiarism which are the normal indicators of research misconduct. Although an "Expression of Concern" was raised, the paper in question was never formally retracted. The major issue raised by Edwards and Frankel was that that the findings are at odds with conventional corrosion theory and many previous (and later) studies of galvanic corrosion in copper-lead piping. Edwards does, however, find some examples of poor research practices relating to the collection, storage, analysis and presentation of data. The authors were not able to explain adequately how the visual appearance of graphs changed over time, how and when the data was collected, nor did they supply copies of the original data for inspection as requested. The journal reviewers may also have been either negligent or unfamiliar with fundamental aspects of corrosion science, especially the theory of galvanic corrosion mechanisms.

The second example appears to be a blatant case of data fabrication and falsification involving a large number of papers, over an extended time period and published in reputable electrochemistry and corrosion journals. The review analyses seems to show clear evidence of systematic data fabrication, and the rebuttal hardly addresses the most significant issues. In many instances, the authors of the original papers seem to have taken corrosion data and simply rescaled it to generate additional data sets that nominally reflect changes in the experimental conditions. This data fabrication technique has been applied variously to weight loss measurement, polarisation and EIS plots. Digitisation of the data sets typically shows that they are exact ratios of each other – even though there is no plausible physical explanation for this to be the case. For linear plots these manipulations are often obvious, but for more complex curves (such as polarisation and EIS plots) these are often much more difficult to detect without a detailed analysis. Finally, there are many examples of extremely precise and highly linear data (e.g. weight loss measurements) presented in the papers, where even a cursory review of the corrosion literature will indicate that this is exceedingly unusual and, given the nature of corrosion processes, extremely unlikely.

It is useful to relate example 2 to the case of Hendrik Schön [9] who used very similar techniques to fabricate results on a wide range of semiconductor devices. The authors of the report investigating allegations of Schön's misconduct asked: "Is there clear evidence that the data does not come from the measurements described?" The first evidence they identify is *data substitution* "…in which data sets for distinct experimental conditions show unreasonable similarity to each other, in some cases after multiplying one data set by a constant factor". In the publications of Schön there are many examples where results are multiplied or rescaled by a constant factor (often an integer) to generate additional data. This is precisely the kind of data fabrication identified in the second example. Additionally, the authors of the report discuss the concept of *unreasonable precision*, as an indicator that data does not come from direct measurements. It is clear that the weight loss data reported in example 2 could be considered an example of this. Similarly, the Tafel parameters ($b_a$ and $b_c$) reported often show remarkable consistency ( ±1.5 mV $dec^{-1}$) over a wide range of conditions, and this could also be considered an example of suspicious and/or unreasonable measurement precision.

The third and final case presents several examples showing a range of misbehaviours in publications that are clearly in breach of good scientific practice. Ranging from appropriation of another person's data, self-plagiarism (re-use of the same figures and data in different journal articles) to improper attribution of authors without their consent, these are all unacceptable practices.  However, unlike the papers discussed in the second example, all of these papers were retracted and the issues clearly made apparent for the discernment of other researchers.

In practise, research integrity issues exist which are of more widespread concern than the narrow interests of the researchers themselves. Other stakeholders in the research sphere include funding agencies, industry partners, conference organisers, journal publishers, editors and reviewers and ultimately the consumers or public who may  be affected by the research findings. All need to be aware of such issues which can not only damage the reputations of individuals but of institutions as well and can be viewed as a betrayal of trust. A 2016 paper [50] highlights many of the reasons for scientific misconduct which has become more prevalent in recent times. For example in life sciences and biomedical research the percentage of articles retracted has increased by 1000% since 1975, with 67% being due to misconduct, including fraud and suspected fraud (43.4%), duplicate publication (14.2%) and plagiarism (9.8%). The costs of scientific research misconduct are significant. The direct costs of handling a research misconduct case is US$525,000 with over US$110 million incurred annually at the institutional level in the USA. Such results led the journal *Nature* in 2015 to state that "pretending research misconduct does not happen is no longer an option".

Several reasons for such practices have been advanced including the notion of "perverse incentives" arising from the need to achieve targets through quantitative performance metrics, sometimes at the expense of research quality and the "hypercompetitive funding environment" [50]. In the latter case more researchers are now applying for a diminishing pool of funding as has happened in the EU with its latest H2020 funding scheme claiming a success rate of only 14% (less than 1 in 7). Together with institutional requirements to improve global rankings and the concept of academic freedom to pursue risky ideas diminishing, (the "trampling of the scientific ethos") enormous pressure has been brought to bear on researchers. Consequently there is a strong temptation to engage in dubious research practices. One survey reported in Edwards and Roy [50] conducted in 1989 noted that 34% of researchers had engaged in practices such as "dropping data points on a gut feeling" and "changing the design methodology and results of a study in response to pressures from a funding source". It would be surprising if the percentage had not increased since then.

Research integrity issue can be tackled on many fronts. As indicated by the examples in given in section 2 science is still essentially a self-policing activity. It has largely been other scientists or domain experts, who have highlighted research misconduct issues in published articles. In conjunction with the pressures faced by researchers highlighted above and with a rapid increase in journal numbers, including open access journals where researchers pay for publication, there is a need for more journal editors and reviewers. However, many of the reviewers lack experience or expertise meaning that it is likely that more reports of research misconduct will appear. Publishers are well aware of this and have set up a forum for editors and publishers of peer reviewed journals to discuss all aspects of publication ethics (Committee on Publication Ethics, COPE) [51].  Established in 1997 by a small group of journal editors it now has over 10,000 members worldwide from all academic fields. Although COPE does not investigate individual cases, it actively encourages editors to ensure that cases are thoroughly investigated by an employer or research institution such as a university. Use of computer tools such as digitisation of data and data analytics and other methods can assist this work through identification of unexpected trends. Another publication issue is the re-use of digital images in multiple publications, which is a problem especially in the biomedical field and is more prevalent in higher impact journals.

Research funders themselves are also highly aware of research integrity issues. Following such misconduct cases there is a strong move for original research data to be available for researchers and others to interrogate. Notwithstanding difficulties such intellectual property rights and commercial constraints, the concept of Open Science has been promulgated as a way to peer-review and authenticate data. However this has been difficult to carry out and is still under development.

A variety of approaches aimed at tackling this important issue are being adopted ranging from training of PhD students to monitoring of research outputs and validation of results. More difficult to achieve is the need to reduce "perverse incentives" such as the favouring of quantity of outputs over quality, especially in the very competitive funding environment that currently exists and the need to actively discourage unethical behaviour in favour of the pursuit of the practice of science in the service of humanity. Such challenges apply to all scientific fields including Corrosion Science.

## 4. CONCLUSIONS

Research integrity which covers more than just ethical behaviour is becoming more important in science, especially in the biosciences and health/life sciences. Several cases of alleged research misconduct reported in the open literature indicate that although it is not yet a big problem in corrosion research, it has occurred. This makes it extremely important that various research stakeholders such as funding organisations, journal editors and reviewers and above all researchers themselves are fully aware of this issue and its ramifications.

The three examples of alleged research misconduct presented demonstrate different levels ranging from plagiarism to serious data fabrication. In the first example it could well lead to serious public health damage. Critical judgments on the quality of research work presented in peer-reviewed papers is necessary to prevent dissemination of potentially incorrect and/or possibly harmful results and it is up to all researchers to contribute, both as researchers and as reviewers and evaluators of research proposals and peer-reviewed papers.

Real corrosion data will be inherently noisy, as unlike a normal electrochemical working electrode (e.g. Pt, Au) which remains dimensionally stable (apart from adsorption), a corroding working electrode undergoes spatial and temporal changes. Processes such as film formation and removal, dissolution, intermetallic particle detachment and metal detachment will take place on a corroding electrode over a period of time. In practice this may well lead to significant amounts of random errors, especially in gravimetric and electrochemical data. Such inherent variability is well understood by most corrosion researchers. Therefore it is both surprising and disappointing that abnormally invariant data reported in many papers identified in the second case has not been questioned more vigorously by journal editors, referees/reviewers or indeed by other researchers.

It is important that journal editors and reviewers possess the requisite expertise and experience to identify possible fraudulent or fabricated data and plagiarism issues. The use of a simple digitisation analysis is one method of detection as was performed in the second example presented. Image processing techniques are routinely used by scientific publishers to detect manipulation of images, so it not unreasonable that such approaches could be applied to other forms of data. However it is important to note that, in many cases, the fabrication of data appeared to be so obvious that simple visual inspection should have been sufficient to arouse suspicion. Quality testing of journal reviewer's competence may also be a helpful initiative to help prevent such occurrences.

There are now many on-line resources for dealing with scientific misconduct. For example, the blog "Retraction Watch" includes an analysis and commentary on publications that have been recently retracted. Similarly, the website "Pub-Peer" allows researchers to anonymously review and discuss published research. In many cases, such discussions have led to the identification of scientific misconduct and the retraction of papers. Most scientific publishers have developed standardised procedures for handling ethical allegations relating to issues such as plagiarism, authorship, conflicts of interest and data fraud or falsification as illustrated in the third example. With such resources and procedures now available, there are no real impediments for scientists and researchers to raise legitimate concerns about suspected research misconduct.

The reasons for such unscrupulous behaviour (research misconduct) can range from Langmuir's "pathological science" and willingness to suspend objective judgement of the work's quality in order to gain attention and advance one's career, to more sinister motives, sometimes for financial benefit. This has become a major problem throughout science over the past few decades. In an increasingly competitive funding environment this has caused severe pressure on researchers leading occasionally to unethical behavior.

Vigilance and adherence to the requisite high standards for research will prevent instances of willful research misconduct and save science's reputation for being trustworthy and reliable. This is vitally important as each case undermines its integrity and future prospects and diminishes its status in the public domain.

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