

Digital Print technologies and their relation to Vitreous Enamel on metal for the visual artist.

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Abstract

The Centre for Fine Print Research at the University of the West of England has recently installed a large-scale electric enamelling kiln for firing enamelled panels to be used in public art projects. This has necessitated research into methods of transferring digital photographic imagery printed using vitreous enamel onto steel and copper flanged panels. The panels have to be light fast, vandal proof and be able to withstand outdoor weather conditions for approximately thirty years

In order to obtain the best quality photographic rendition and to guarantee accurate registration large-scale decals have to be used. Two primary methods of transferring a digital image to a decal have been investigated to date. The investigation compares commercial electrostatic ceramic decals to a new screen-printed decal system patented by the CFPR. The problem is a balance between ink deposition, photographic rendition, thermal shock effects and particle size and deposition.

Microphotographs comparing decals before and after firing to ascertain strength of deposition, colour quality and ability to flux with the basecoat demonstrate the results. Some of the problems encountered will be discussed and examples of public art projects completed as a result of the study will be demonstrated.

Introduction

Much confusion exists over the word "enamel" since it is used to describe glazed surfaces in many kinds of material, including teeth, paint, varnishes and resin (cold enamel) finishes. For the enamellist, ceramicist, glassmaker and metal smith, enamel is a glass.

It is assumed as with most early technologies, that the first enamels resulted from an accident. Powdered or small fragments of glass were heated on metal and found to melt and coat the metal with a permanent, brilliant, jewel-like colour surface. Enamel has been fused to metal for at least 4,000 years. [1]

Enamel or vitreous enamel on metal is a thin layer of powdered glass re-melted by heat onto the surface of a metal. These tiny coloured glass particles are fused to the red hot metal at 1472°Fahrenheit (800°Celsius). The firing time is depended on the size of the piece to be fired and the size of the kiln, it can be as short as 30 seconds for small objects of thin metal and up to 10 minutes for large panels of steel or stainless steel.

The word enamel comes from the High German word 'smeltzen' and later from the old French 'esmail'. Enamel is part of everyday life and is found all around us. Items such as stoves, saucepans, and architectural cladding are all enamelled,

A recent development creates a non-stick enamel base for steam irons. It has also been traditionally used as a covering for iron and steel baths and faces of clocks and watches. Artists and jewellers have used enamel since the 15th century.

Printmaking techniques have been used on enamel fused onto copper since the 18th century. An important English contribution to the development of industrial or mass produced enamel was the invention of the process of printed transfers (decals), which were applied and fused to a pre-enamelled copper-based object. These small artefacts and trinkets were pressed from thin copper sheet and coated with a dense base coat of white enamel, when this coat was fired it gave strength to the fragile forms and produce an excellent background for the printed image. The decoration or image was applied mainly by transfer printing, a cheap quick method using engraved copper plates to make transfer prints for hundreds of items without the need to employ specialist painters. The paper used for the transfer was a fine tissue; that was thin, strong, smooth, hairless and non-absorbent.

For our purposes print in enamel started when the first factory to produce transfer-printed designs on enamel was set up in Battersea in 1753 by Stephen Janssen, a wealthy entrepreneur. He employed John Brooks, who managed the factory and is credited by some with the invention of the transfer method. The famous French engraver Simon Francois Ravenet was commissioned to make the copper plates for printing the transfers. The colour ranges for the transfers were black, red, sepia and brown. The printed designs could also be painted with over-glaze / on glaze colours.

In the 1890's a method was invented to reproduce photographs in black or sepia onto vitreous enamel, based upon bi-chromated gelatine, with the addition of enamel pigment; these pieces often had additional colour added by hand. Screen-printing was introduced in the early 1920's and this meant stencilling, printing and photography could now be combined in one piece. From the end of the 19th century the process was used commercially to produce large-scale signs including advertisements, street names, railway and underground signs in relation to these exterior applications, this paper will concentrate on enamel on metal used in a public art context. Its abilities to withstand outdoor weather conditions make it ideal for large exterior architectural artworks and its ability to be aggressively cleaned make it very practical within for use with in public art hospital projects.

The process of firing enamel on a metal panel on steel

Steel used for enamelling should be of a very high quality with little or no impurities and a very low carbon content, usually less than 0.2 percent. The metal first has to be degreased and a fine surface tooth applied, usually by shot or sandblasting. A base coat

of enamel called a grip coat is applied to both sides of the metal. This layer serves several purposes, it creates a continuous coating which prevents the steel rusting once the panel is completed, improves the adhesion and brilliance of the coloured enamel layers to the base metal, and prevents warping by equalising the tensions of the enamel during the firing process. Once the grip coat has been applied a secondary, usually white, base coat is applied to the upper side and fired. The white acting as a reflective coat to improve the quality of colour printed on top. Finally the printed layer is applied on top of the white and this is then fired to produce the printed result.

Traditional methods of printing enamel panels

Since the early part of the 20th century, enamel on metal panels has been directly screen-printed. Screen-printed was highly suited for printing enamel on metal due to its ability to deposit large size particles on average between 10 and 25 microns in a controlled but heavy deposition layer. This ability meant that a rich dense flow of colour, which was permanent, in lightfast terms, could be achieved. Historically photographic imagery was transferred to the screen stretched with a silk mesh using a bi-chromated gelatine. Once the gelatine layer had been developed and dried the screen would be made waterproof by applying a thin coating of shellac and mopping the excess from the mesh of the screen. The enamel pigment was mixed with a printing medium and forced through the open mesh of the screen with a rubber blade known as a squeegee.

Why use a decal?

It is perfectly possible to screen-print enamel ink directly onto the surface of the metal and commercially the large majority of street signs are printed in this way. The reasons for using a decal are many, primarily it is easier to register and re-register a sheet of paper upon which multiple colours are printed and dried in between each printing, than it is to re-register a metal sheet or object. Secondly if the surface is not flat or has any compound curves it is not possible to directly screen print. In this case it is much easier to apply a water slide decal to the surface.

Traditional screen-printed decal (transfer) systems

In the late 1930's when H and R Johnson of Stoke-on-Trent, England first patented a screen-printed on glaze enamel water slide for ceramics patent no. 471219(1937) Johnson Matthey & Co. Ltd. Hatton garden, London, in the UK a decal is commonly known as a transfer and so both terms are used interchangeably. Screen-printed ceramic decoration for tableware has been one of the main processes of the ceramic industry. Commercially this process has changed little since the first patent. It consists of a waterleaf wet strength paper support layer (this akin to blotting paper as it has no sizing or chin clay element). This support layer is coated with gum or agar, which is water-soluble. This gummed paper layer is then screen-printed with the image; the ink for the image consists of enamel on glaze pigment mixed into a pine oil medium. When the required number of colours have been printed and dried a cover coat support layer is then applied, thus completing the decal. This cover coat support is a plastic flexible membrane. When the completed decal is placed in a bowl of water, the water is absorbed through the waterleaf backing and dissolves the gum layer. The plastic cover coat support layer then lifts free carrying the printed enamel image. The decal is then applied to the surface of the ceramic artefact. The gum layer acts as a temporary glue to support

the decal. When dried and fired to a temperature of between 1400° and 1490° Fahrenheit (760°C and 810° Celsius) the decal will burn away and the over-glaze / on-glaze enamel become fluid at around 1328° Fahrenheit (720° Celsius) and will achieve a gloss at between 1400° and 1490° Fahrenheit (760° and 810° Celsius). The enamel glaze has by this point become an integral part of the under-glaze layer. The plastic cover coat layer will have burnt off and disappeared at approximately 932° Fahrenheit (500° Celsius).

Laser printed transfers

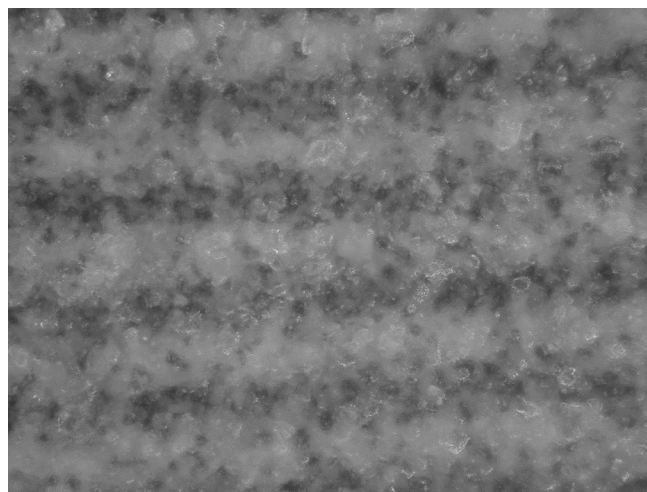


Figure 1: Microphotograph, Unfired laser transfer not characteristic banding

In the last five years, commercially available decals for on glaze ceramic decoration using an electrostatic laser printer have been developed. The four colour process toner is replaced with a toner which has enamel pigment included. This is a finely ground enamel where by necessity the particle is an agglomeration of pigment plasticizer and other elements that make a toner particle. The size of the agglomerated particle is less than 10 microns as any larger would be hard to transfer electro statically. As can be seen from the attached diagram of laser scanned reflective light analysis, the deposition layer of pigment and flux medium varies between 10 and 15 microns. The initial problems of the metal content within the enamel particle have been solved and an even deposition layer is created. Once the particle has been deposited on the substrate and fused, a further cover coat and extra flux layer are applied. The base paper for the process is the same as for a traditional screen-printed decal and is again a wet strength waterleaf sheet with a coating of agar gum. From the enlarged unfired microphotograph it is possible to see the characteristic stripping of laser print deposition. It is interesting to note, that this fires away and in the microphotograph of the fired sample, it is clear that the very even fine dot structure is achieved.

This process has become extremely useful for short run promotional and point of sale materials as well as to the designer/crafts person who wishes to make a one off or bespoke artefact. The major problem of this process compared to screen-printing is the depth of the deposition layer.

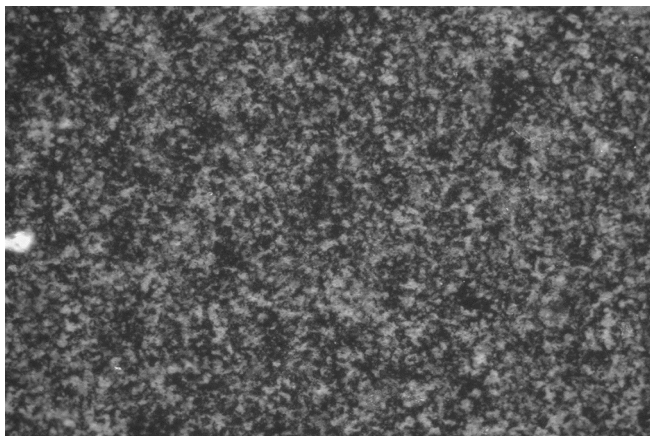


Figure 2: Microphotograph. Fired laser transfer

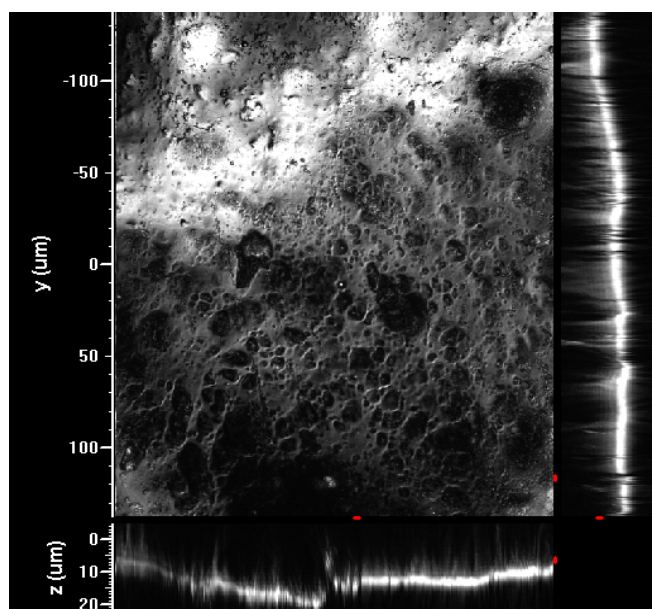


Figure 3: Particle size of laser transfer using reflected light LSCM2

Whilst it is possible to create accurate (given the limitations of creating a CMYK colour set at temperatures of 800 degrees) photographic rendition by this process, the quality and richness of colour is very poor in comparison to the much heavier screen-printed deposition. The other limitation is the size of the decals available. They are only available in sizes up to A3, 420 by 297 millimetres. This is more than adequate for most small-scale production work, but was found to be restrictive for this project.

Screen-printed transfers

In 1998 the Centre for Fine Print Research, at the University of the West of England (CFPR) filled a patent for a water-based ceramic on glaze screen-printing system. This system differs from the traditional system in that the gummed waterleaf sheet is first coated with the plastic cover coat layer before the image is printed

on top. The image is printed using a water-miscible acrylic medium, which is mixed with the enamel on glazed colour. When dry this layer becomes waterproof. The system works because the acrylic medium burns away at a much lower temperature than the cover coat layer. This system means that there is only one printing cycle for the image to create a complete decal. The CFPR have now extended this process to printed enamel on metal and use the decals to fire on glaze imagery onto steel, copper and silver metal backing.

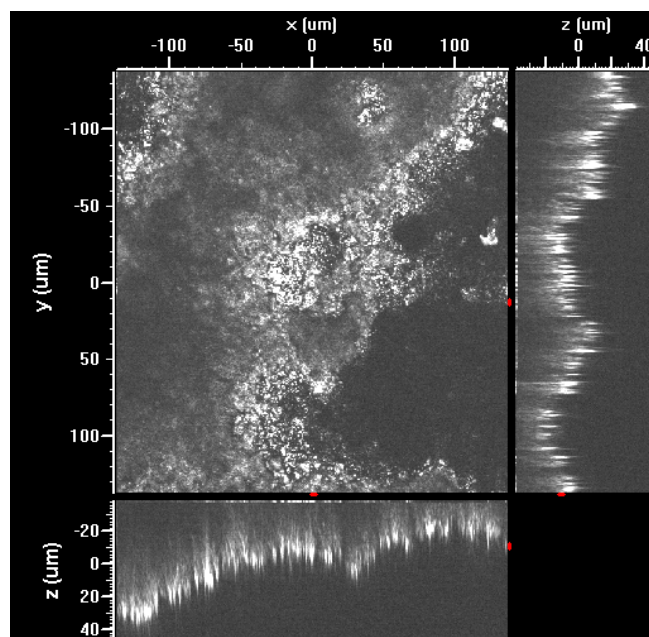


Figure 4: Particle size of screenprint transfer using reflected light LSCM2

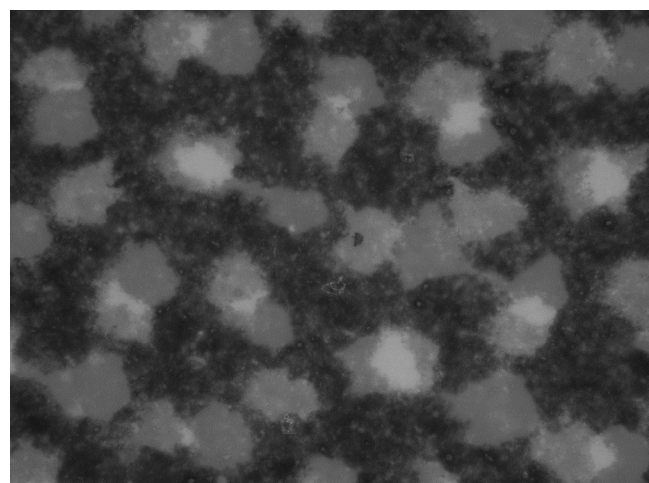


Figure 5: Microphotograph. Screenprint transfer fired

Due to the much larger particle size of the enamel used in this process between 10 and 25 microns on average. As can be seen from the attached diagram of laser scanned reflective light analysis, the deposition layer of pigment and flux medium varies between 20 and 60 microns for the total depth of the screen-printed enamel pigment and printing medium layer. It is not possible to create photographic imagery of extremely high detail. The best quality photographic image easily obtainable equates to a halftone structure of between 75 and 95 lines to the image. Therefore to create a small-scale photographic image the image is first rendered in 'Photoshop' and then a set of halftone films is laser printed in black onto four sheets of Folex transparent laser film. The output is between 75 and 95 LPI with an elliptical dot. From the enlarged microphotographs it is clearly possible to see this dot structure and its appearance. The photographic imagery is much cruder and the printed dots are in the tens of times larger. However once the artefact is fired and the two images screen-print and laser, are placed side by side, most viewers subjectively prefer the rich colour of the screen-printed layer (up to 4 times thicker). In spite of the enhanced photo quality of the laser print. Subjectively the colour of the laser version is very much duller when fired.

Colour

One of the major problems of transcribing CMYK photographic imagery into enamel is one of colour. Enamel glaze is not particularly translucent and to create anything approaching good quality magenta the base material is gold, therefore cost is a major issue. The problem occurs less with the laser prints as a much thinner deposit is used with little or no waste, so the cost of gold is comparatively small per print. It is easier to create a mid tone red, consequently the cyan and yellow have to be adjusted to compensate. The resulting colour set is always something of a compromise, partially because the reds will fire better closer to the 1400° Fahrenheit (760° Celsius) - temperature range and the blacks fire better at the higher 810 degrees centigrade. A really glossy black can mean the loss of red and conversely a rich red can lead to a matte black. However with a certain degree of profiling the fired result is more varied in the laser print, as a very thin layer is more susceptible to under or over firing.

The problems of firing large-scale decals

When pushing a printing process to its limitations problems will occur. By applying a layer of enamel which is 10 microns or less, where surface thickness of enamel is measured in hundreds of microns, the chances of either over firing and burning off the minute layer, or under firing and not fusing the printed layer to the base coat are very high. Further problems of volatile gasses either escaping or being trapped by the multiple layers are also likely to occur. Added to this the huge degree of expansion which the metal, the glaze and the print under take in a short heat cycle, which is measured in a few minutes, create ideal conditions for thermal shock.

The problems of firing laser printed transfers

Due to the very thin layer, when the transfer is floated free from the backing sheet and applied to the enamel surface. It has been found that the transfer first needs to be dried and all moisture content removed before firing. The second stage requires the gentle removal of the cover coat layer before the full enamel firing takes place. This is achieved by placing the enamel panel and decal in a cold kiln and firing slowly 122°Fahrenheit 50° Celsius) an hour to a

temperature of between 842° and 932° Fahrenheit (450° and 500° Celsius) degrees centigrade. The work is then removed from the kiln and allowed to cool. When it has been ascertained that the cover coat has been burnt away and the enamel glaze is just sitting but is yet unfluxed on the surface of the panel. The panel is then returned to the kiln, now at a temperature of 800 degrees Celsius, for between 4 and 6 minutes to finish the firing and flux the enamel.

This method of firing avoids the problem of gas bubbles escaping from the base coat of enamel and being trapped by the cover coat layer. As can be seen from the accompanying pictures, gas creates an easily identifiable pinprick surface to the image if the above precautions are not taken. Further problems from gas bubbles in this manner can also occur if the metal has been bent or is under stress during firing. Other problems that can occur with the thin laser coated stencils can be a lack of flux in the printed ink or even within the colour coat. To compensate for this further flux or additional flux is added to the cover coat layer. This results in improved firing of the image but the downside is a potential matte surface on the surrounding glaze from the flux

The problems of firing screen-printed transfers

Whilst the deposition layer of a screen-printed transfer is much heavier some firing problems still occur when firing detailed photographic images. This is probably due more to trying retain the medium on the surface and keep it glued down whilst the plastic cover coat layer fires up and through the printed ink layer. The acrylic-printing medium actually rises to the top of the print layer with the enamel particles sinking to the bottom when printed. This can be seen in the microphotograph of the unprinted screen print decal.

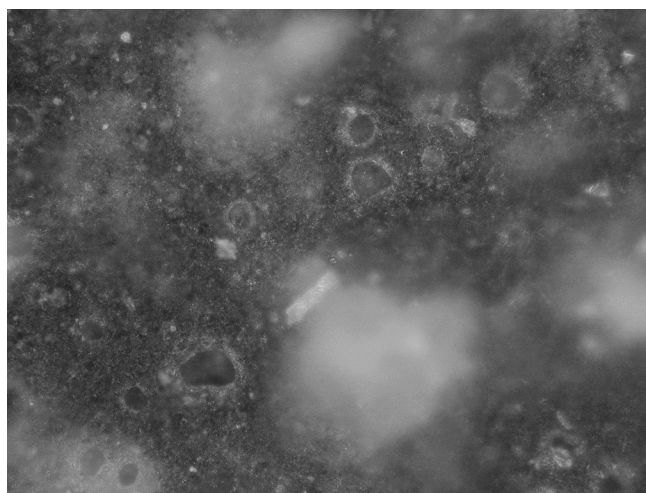


Figure 6: Microphotograph. Unfired screenprint transfer

Two problems can occur regularly, the first is the problem of gas bubbles, which the cover coat layer traps beneath the decal as previously detailed. Further problems can occur if the layers of screen-printing overlap and become quite thick. These can suffer from almost the opposite problem where there is not enough flux in the printing medium to hold them to the surface and the image

can blow away. This can be seen in the accompanying micro photograph, where the underneath support layer has split away from the surface of the metal, creating a hole in the decal when fired. As a precaution if a delicate image is being fired, firing from cold to remove the cover coat layer can assist in a better quality image. However in most cases as long as the decal has been properly dried before firing to remove any moisture a good result can be achieved.

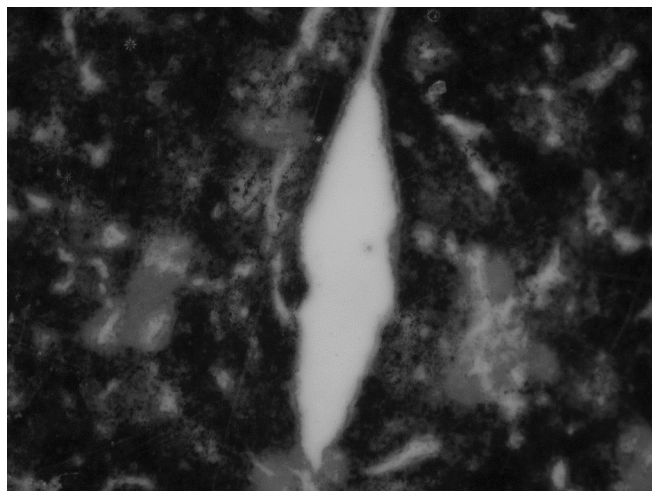


Figure 7: Microphotograph. Screenprint transfer demonstrating lack of flux or gum coating after firing

Conclusion

These experiments have taken place to assess the viability of firing large-scale public art pieces. Both processes work well for small scale panels up to 30 centimetres, but larger steel panels such as the 'Inebriate Owl' by the English artist Ivor Abrahams, illustrated are more difficult. This piece is approximately 1 metre 60 centimetres high. The problems of expansion and differing stresses of metal are much greater; the firing times are also increased to approximately 10 minutes. Therefore whilst a decal has to be used to cope with the compound surfaces presented by a multi part three-dimensional object, the small tolerances for firing laser decals render them almost unusable. The more time consuming process of screenprint and the cruder nature of the photo imagery is offset by the thicker layer and its ability to cope with the longer and more varied firings. In conclusion is it possible to make digitally generated imagery that can be fired onto enamel on metal.



Figure 8: Enamel on steel public art commission 'Inebriate Owl' by the sculptor Ivor Abrahams approx. 5 feet high

References

- [1] Elizabeth Turrell, *Contemporary Print in Enamel* (Impact Press, Bristol UK 2001)

Author Biography

Steve Hoskins is Hewlett Packard Chair and Director of the Centre for Fine Print Research at the University of the West of England, Bristol. He studied at West Surrey College of Art and the Royal College of Art. He has written two books 'Water-based screenprinting' and 'Inks' published by A and C Black. He is vice-president of the Royal Society of Painter Printmakers and a board member of the Association of European Printing Museums.

Elizabeth Turrell has been designing and making enamelled panels for thirty years. She is Senior Research Fellow in Enamel and head of the Enamel Research unit at the University of the West of England, Bristol. She is a Director of the Fusion Gallery London, the UK's first specialist enamel gallery. Elizabeth exhibits both nationally and internationally and undertakes large public art commissions, she has taught workshops in the UK, USA and India.