INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN BUSINESS & SOCIAL SCIENCES
Vol 15, Issue 4, (2025) E-ISSN: 2222-6990

Experiments on the Feasibility of Combining 3D-Printed Metal Base Material with Enamel Glazes

Chen Qingliu[1], Sharul Azim Sharudin[2]
City University Malaysia
Email: 962284624@qq.com, sharul.azimm@city.edu.my

To Link this Article: http://dx.doi.org/10.6007/IJARBSS/v15-i4/25227 DOI:10.6007/IJARBSS/v15-i4/25227

Published Date: 22 April 2025

Abstract
Enameling, as an ancient and exquisite surface decoration technique, is important in jewelry, artwork and industrial products for its vibrant colors, smooth texture and excellent durability. Traditional enameling is usually based on gold and silver and combines glassy enamel with metal through high temperature firing to create a strong and beautiful surface. However, traditional processes have limitations in producing complex structures and high-precision details, and the long production cycle and high cost make it difficult to meet the demand for personalization and efficient production in modern design. In recent years, with the rapid development of 3D printing technology, especially the maturity of metal 3D printing technology, with its high efficiency, precision and flexibility, it provides new possibilities for the innovation of enameling process and revolutionizes the design and production of enameling process. The aim of this study is to explore the process feasibility of combining 3D printed metal substrate with enamel glaze, and to analyze the possibility of combining brass, white copper and purple copper with enamel glaze firing and the influence of the firing effect by 3D printing three kinds of metal materials and combining them with enamel glaze firing experiments to optimize the process parameters and to improve the strength of combining with the aesthetics. Specifically, the study will focus on the following aspects: first, comparative analysis of the surface properties of different 3D printed metal materials and their compatibility with enamel glaze; second, explore the impact of firing process parameters on the strength of the combination of metal and enamel, and optimize the firing conditions in order to reduce the risk of cracking and peeling; finally, through the analysis of the firing data, assess the overall performance of the combination of 3D printed metal substrate and enamel glaze which provides scientific basis for practical application.
Keywords: 3D Printing, Enameling Process, Enamel Jewelry, Metal Material, Jewelry Design

Introduction

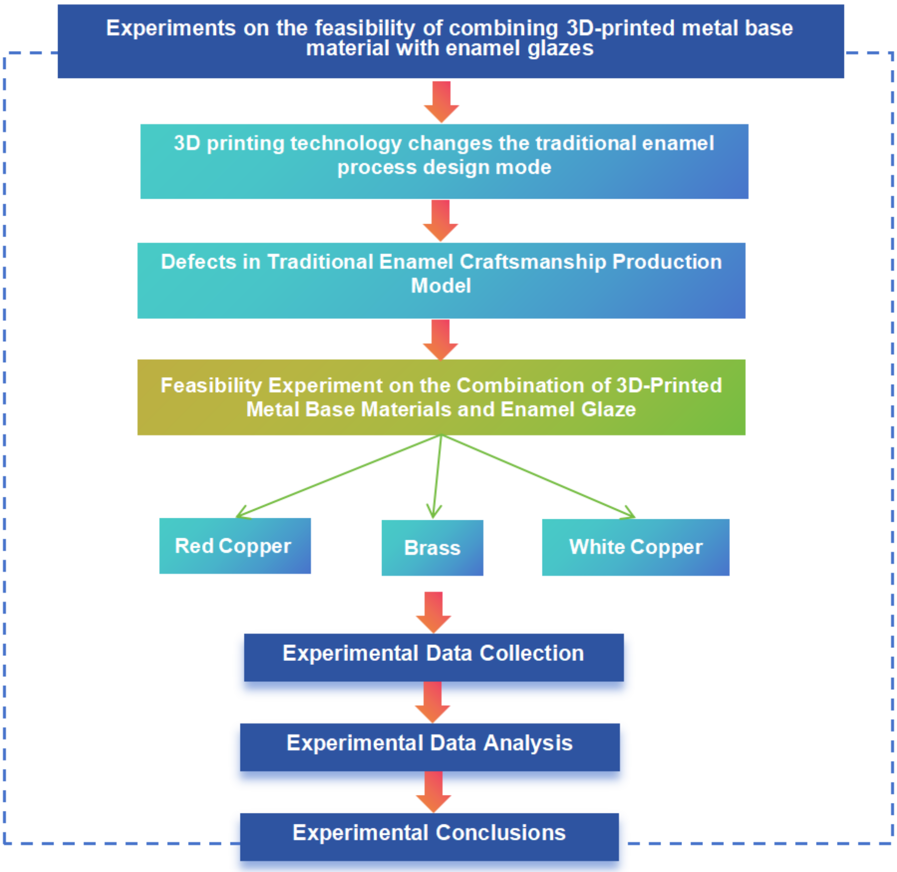
The design process of traditional enameling is highly dependent on the craftsmen's manual skills, from pattern design to filigree and glaze filling, each step requires great patience and skill. Although this mode can reflect the unique artistic value, it also has the limitations of low efficiency, high cost and difficult to replicate.The introduction of 3D printing technology has completely changed the situation. It not only simplifies the production process, but also realizes the automation of part of the process.

The high-precision nature of 3D printing technology makes the detailed performance of enamel products more perfect. Whether it is the fineness of the filigree or the uniformity of the filling of the enamel, 3D printing technology is able to reach a level that is difficult to reach by traditional hand. This increased precision not only improves the quality of the product, but also enhances its artistic expression.3D printing technology can be combined with the traditional enameling process to create a new production mode. For example, a metal substrate can be created through 3D printing, and then enamel glaze can be filled and fired on its surface. This combination of processes retains the artistic value of traditional enameling while incorporating the efficiency and precision of modern technology.

The traditional enameling process has certain limitations in the choice of materials, mainly relying on metal substrates and glassy glazes, usually using precious metals such as copper, silver and gold as the substrates, which are not only costly, but also easy to be oxidized or deformed during processing, increasing the difficulty and cost of production. The introduction of 3D printing technology, however, provides more possibilities for the choice of materials for the enameling process.3D printing technology supports the printing of a variety of metal materials, such as copper alloys, aluminum alloys and so on. These materials not only have excellent mechanical properties, but also can be perfectly combined with enamel glaze through surface treatment, thus expanding the application range of enamel products.

Research Method

This study is based on the quantitative research method, through reviewing relevant literature at home and abroad to understand the current status of the application of 3D printing technology in the field of jewelry, and analyzing the advantages and disadvantages of the existing enamel jewelry production process. Before carrying out the experimental research on the feasibility of combing 3D printed metal base material and enamel enamel, through the combing of domestic and foreign related literature and the analysis of existing cases, we can comprehensively understand the current situation of the application of 3D printing technology in the field of jewelry, and at the same time, we can deeply analyze the advantages and disadvantages of the traditional enamel jewelry production process, so as to provide the necessary theoretical support and practical reference for the subsequent research, and we adopt the experimental method, which is respectively for Three kinds of metal materials, namely, purple copper, brass and white copper, are used as metal substrate materials for enamel jewelry to explore the feasibility of combining different metal materials with enamel glaze firing.
The specific technical routes are as follows(Figure1):



(Figure1)Experiments on the feasibility of combining 3D-printed metal base material with enamel glazes
Image source: Photographed by the author

Material Testing and Compatibility Study
Selection of various 3d printed metal materials and enamel materials for compatibility testing to determine the best material combination and process parameters
In the experimental study of the feasibility of combining 3d printed metal base material and enamel enamel based on 3d printed metal base material, the selection and compatibility of the material is one of the key factors in determining the quality of the product and the production efficiency. The production of enamel jewelry involves the combination of metal substrate materials and enamel glaze, and the introduction of 3D printing technology puts forward higher requirements on the compatibility of materials. Therefore, this study will conduct systematic material testing and compatibility studies to explore the optimal combination of 3d printed metal materials and enamel glazes suitable for enamel jewelry production and determine the corresponding process parameters.

Material Selection
3d printing metal materials: the selection of 3d printing metal materials must consider its compatibility with enamel glaze, mechanical properties and performance. Commonly used 3d printing metal materials include silver alloys, copper alloys and so on. These materials have obvious characteristics in terms of hardness, ductility, high temperature resistance, etc., which need to be verified through experiments to assess their bonding effect with the enamel. Enamel glaze is the core material of enamel jewelry, and its composition and firing temperature directly affect the color and texture of the final product. Common enamel glazes

include transparent glazes, opaque glazes and translucent glazes. Different enamel materials have different firing temperature ranges, which must be matched with the high temperature resistance of 3d printed metal materials.

Compatibility Test

The main purpose of the compatibility test is to evaluate the adhesion effect between the 3d printed metal material and the enamel glaze in the high temperature firing process, including adhesion, color properties and surface smoothness.

The specific test steps are as follows:
Sample preparation: use a 3D printer to make substrate samples of different metal materials to ensure a smooth surface without obvious defects. Then, various types of enamel glazes were uniformly applied to the metal substrates and initially dried.

High-temperature firing experiment: The enamel-coated samples are fired in a high-temperature furnace, and the firing temperature is set according to the enameling requirements. The heating rate and holding time must be strictly controlled during firing to prevent deformation of the metal substrate or cracking of the glaze.

Performance evaluation: After firing, the samples are evaluated for comprehensive performance, including adhesion test: using cross-cutting method or tensile test to evaluate the bonding strength of the glaze with the metal substrate. Color and Gloss Measurement: Measurement of glaze color properties and surface gloss by colorimeter and gloss meter. Surface defect analysis: Observe the sample surface with microscope for cracks, bubbles, and flaking.

Process Parameter Optimization

Based on the compatibility test, further optimize the process parameters of 3D printing and enamel firing, including:

Enamel firing parameters: e.g., firing temperature, heating rate, holding time, etc., to ensure uniform melting and good adhesion of the enamel glaze.
Through material testing and compatibility studies, the most suitable combination of 3d printed metal materials and enamel glazes for making enamel jewelry is determined, and the related process parameters are optimized. This not only improves product quality and consistency, but also provides a scientific basis for subsequent standardized production. In addition, this study provides a reference for the application of 3D printing technology in other traditional craft fields, which has important theoretical and practical significance.

Data Analysis

In order to explore the combination effect of different metal materials and enamel glaze, I have carried out a series of firing experiments, aiming to find out which metal materials can be well combined with enamel glaze, so as to provide a scientific basis for the application of enameling process, this experiment is only brass, white copper, purple copper to do with enamel glaze and enamel glaze related to the feasibility of combining the firing experiment.

Brass and White Copper

Brass is an alloy of copper and zinc, the color is golden yellow, the melting point of brass varies depending on the specific composition, generally between 800℃ and 1000℃, white copper is a copper-based alloy, the main added element is nickel, silver-white, metallic luster, good corrosion resistance, able to resist the erosion of most acids, alkalis and brines, respectively, with brass and white copper as the base material for the enamel glaze firing Experiment, the results show:

As shown in Figure 2, the left side of the white copper substrate, the right side of the brass substrate, the size of both 25mm * 17mm * 1mm, and at the same time put into the enamel furnace, after 750 ° C firing 2′, the glaze is completely melted, the firing effect is better, no bubbles and holes, the color is bright and clean and free of impurities, and the surface shows a glassy luster. As shown in Figure 3 & Figure 4, when the glaze temperature drops cooling, move the fired sheet, glaze shedding, shedding state for the glaze whole piece and substrate peeling, glaze intact without cracking, no glaze adherence to the substrate, glaze at the bottom of a layer of oxidation layer attached to the bottom surface of the complete oxidation of the state, the results of firing experiments show that the enamel glaze and brass and copper and white copper both repel, can't be good bonding, brass and white copper is not suitable for as an enameling The brass and white copper are not suitable as the base material of enameling process, and do not have the feasibility of combined firing.

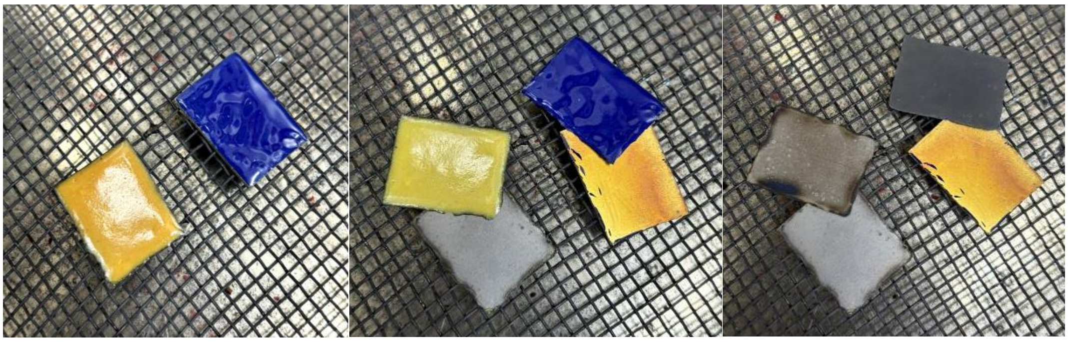


Figure2 Figure3 Figure4

Firing Effects of Combining Brass and White Copper with Enamel.
Image source: Photographed by the author

Problem analysis: In the experiment of metal material substrate and enamel firing, the combination of white copper and brass with enamel glaze is not effective, the main problems are in the following aspects:

① Material properties

The elastic deformation characteristics and high shrinkage of brass: the elastic deformation of brass is more obvious in the process of heating and cooling, and the elastic deformation of brass is still very serious after heating and cooling. This means that brass will rebound and distort after cooling, resulting in the enamel being bounced off the surface and unable to adhere firmly to the metal surface. Brass has a high shrinkage rate, especially H62 brass, which is so high that it requires the use of specialty high shrinkage enamels to barely bond.

The alloy composition of white brass is weak in oxidation resistance and complex surface treatment process: although white brass has good oxidation resistance and corrosion resistance, its alloy composition is easy to oxidize at high temperature, affecting the adhesion effect of enamel glaze, the surface treatment of white brass is more complex, requiring special passivation treatment to prevent oxidation and corrosion. If not properly handled, the enamel glaze can not be uniformly attached to the metal surface.

② the effect of oxide film: brass and white copper in the air is easy to form oxide film. Brass surface will generate a mixture of zinc oxide and copper oxide film, white brass surface will generate a mixture of nickel oxide and copper oxide film. Such oxidized film will have an impact on the combination of enamel and metal substrate, weakening the adhesion between the two, the enamel enamel in the metal surface spread and penetration of the formation of obstacles.

③ Higher cleaning requirements: If there are impurities such as oil, dust, etc. on the surface of brass or white brass, and if they are not thoroughly cleaned before applying the enamel, these impurities will separate the enamel from the metal substrate, making it impossible for the enamel to bond with the metal tightly.

Red Copper

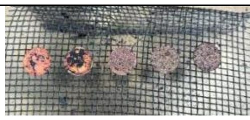
Firing Experiments on Deformation Resistance of Violet Copper Material

Red copper is a pure copper material, named for its purplish-red surface. It has excellent ductility and plasticity, and can be processed into a variety of complex shapes, which provides a rich creative space for enameling. Copper also has excellent thermal conductivity, which allows the heat to be evenly distributed during the high-temperature firing process, preventing the enamel from cracking or blistering due to uneven heating. In addition, the surface of copper is relatively rough, which can provide good adhesion for enamel glaze. Although copper violet tends to oxidize in the air, forming a patina, this property does not negatively affect the final piece during the enameling process because the enamel glaze completely covers the surface of the copper violet, providing protection. The high melting point of copper violet (around 1083°C) and its ability to withstand the high temperatures required for enamel firing (usually between 750°C and 850°C) make it one of the ideal substrates for the enameling process(Figure5&Figure6).


(Figure5&Figure6)Copper sample. Image source: Photographed by the author.

For the different thickness of the copper sheet firing deformation resistance experiments, take the diameter of 15mm, the thickness of 0.2mm, 0.4mm, 0.6mm, 0.8mm, 1.0mm round copper sheet, set the temperature at 750 ° C, 800 ° C, 850 ° C, 900 ° C, respectively, firing 1′, 2′, 3′, to observe the appearance of the copper sheet deformation, experimental results in the form of the Table1:

Table1
Deformation Resistance Firing Experiment of Purple Copper Sheets with Different Thicknesses

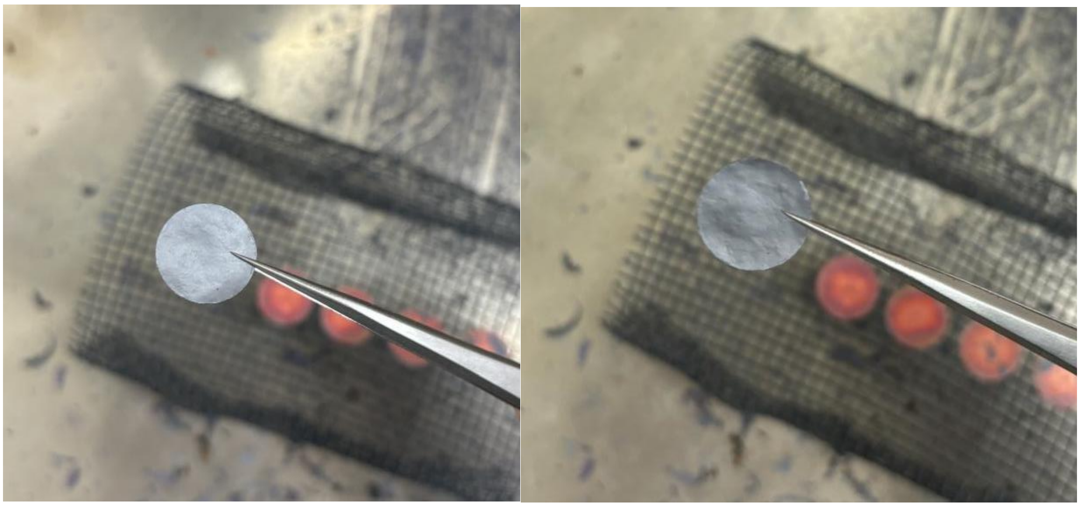
Deformation Resistance Firing Experiment of Purple Copper Sheets with Different Thicknesses			
Firing Temperature	Firing Time		
750℃	1′	2′	3′
			
800℃			
850℃			
900℃			

Experimental Conclusion

When the zinc copper sheet in 750 ℃, 800 ℃, 850 ℃ firing 0.2mm, 0.4mm, 0.6mm, 0.8mm, 1.0mm thickness of copper sheet in 1′, 2′, 3′ time are not obvious deformation, the size can be used for conventional enamel glaze firing, the thickness of copper sheet will not affect the effect of glaze firing.

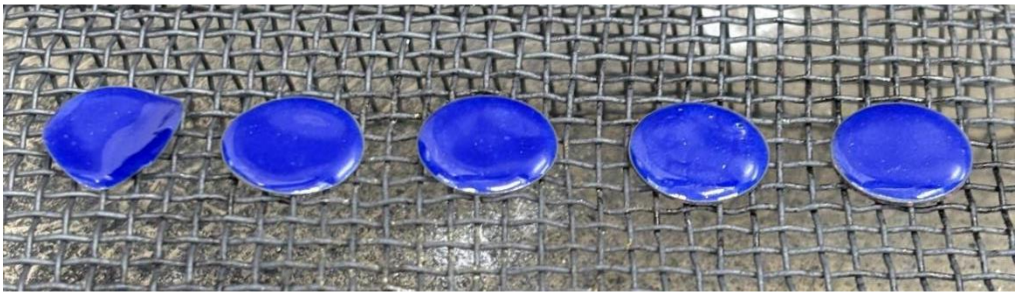
In the 900 ℃, 3′ firing resistance to deformation experiment, 0.2mm thickness of copper sheet deformation occurs to a slight degree (as shown in the figure 7 & figure 8), 0.4mm, 0.6mm, 0.8mm, 1.0mm thickness of copper sheet are not obvious deformation.

It is worth noting that, 0.2mm thickness of copper in the 750 degrees Celsius firing experiment, the surface oxidation layer can naturally fall off when cooling, in 800 ℃, 850 ℃, 900 ℃ firing, the surface oxidation layer and the substrate bonded tightly, cooling can not be naturally fall off, you need to use a steel ball or copper brush scrubbing clean.



(Figure7 & Figure8) Deformation degree of 0.2mm copper sample after firing at 900℃ and 3 '
Image source: Photographed by the author.

Copper Samples Enamel Firing Experiment
After obtaining the firing data of purple copper sheet, next for different thickness of purple copper sample for enamel glaze firing experiments, used to observe the firing effect of the combination of purple copper sample and enamel glaze, the size and thickness of the purple copper sample were 0.2mm, 0.4mm, 0.6mm, 0.8mm, 1.0mm, diameter of 15mm, fill in the purple copper sample with the same color, the same thickness of the enamel glaze, by the 750 ℃, 1'30" into the furnace firing, enamel glaze all melted, the surface is clean and bright, bright colors, high gloss, no bubbles and holes, the glaze is full of cracks, the glaze does not fall off the phenomenon of purple copper samples and enamel glaze firing fit tightly, combined with a strong and has a very high decorative value, which shows that the purple copper material can be used as purple copper material can be used as the carcass of enamel jewelry, the production of a variety of exquisite enamel jewelry, such as rings, pendants, bracelets, hair ornaments, earrings, etc., and can be widely used in the production of a variety of decorative and enamel crafts(Figure9 & Figure10).



(Figure9) Deformation Resistance Firing Experiment Diagram 1of Red Copper Samples
Image source: Photographed by the author.

(Figure10) Deformation Resistance Firing Experiment Diagram 2 of Red Copper Samples
Image source: Photographed by the author.

(Figure11) The image on the left is Deformation Degree of 0.2 mm Purple Copper Sample Fired at 750°C. Image source: Photographed by the author.
(Figure12) The image on the right is Deformation Degree of 0.4 mm Purple Copper Sample Fired at 750°C. Image source: Photographed by the author.

Anti-deformation test results: 0.2mm thickness of copper samples after firing serious deformation, visible edge of the copper sheet warping obviously, the copper sheet has been significantly deformed(Figure11), 0.4mm thickness of copper samples after firing slight deformation occurs, the sample in the middle of the depression, around the convex(Figure12), deformation and 0.2mm samples compared with the slight deformation of 0.6mm, 0.8mm, 1.0mm copper samples to resist deformation is better! The base is flat, the glaze is full, and there is no deformation.

Experiments show that: copper base sample thickness in 0.6mm above is more ideal, the degree of resistance to deformation is better, can be used as the thickness of enamel base material firing, while the base material thickness is lower than 0.6mm will occur to varying degrees of deformation phenomenon, is not suitable for use as the thickness of the enamel base material, as shown in the table below:

Table2
Experimental results of firing of copper sample enamel glaze

Experimental results of firing of copper sample enamel glaze					
Firing temperature	Sample thickness				
750°C	0.2mm	0.4mm	0.6mm	0.8mm	1.0mm
Deformation resistance	serious deformation	Slight deformation	The base is flat without deformation	The base is flat without deformation	The base is flat without deformation
Product suitability	Not Applicable	Not Applicable	Applicable	Applicable	Applicable

Experimental conclusion: the thickness of the metal substrate material has a crucial effect on the enamel firing effect,

① Heat conduction and temperature uniformity: thinner metal substrate heat conduction speed, the substrate material heat uniformity is better, the glaze can quickly reach the molten state, is conducive to the flow of the glaze and adhesion, but too thin substrate material may lead to the local temperature is too high, prone to produce the glaze flow, accumulation of glaze, metal substrate deformation and other Problems.

② glaze adhesion: thinner metal substrate, the coefficient of thermal expansion and glaze match poorly, the cooling process is prone to stress, resulting in glaze cracking or flaking, and thicker metal substrate structure is more stable, can better withstand the glaze's thermal expansion and contraction, reduce the risk of glaze cracking, improve the adhesion of glaze.
③ Glaze effect: thinner metal base glaze is easy to form a close combination with the base material, the glaze effect is more delicate, suitable for making light and delicate enamel products, thicker metal base glaze is easier to form a uniform glaze layer, suitable for making enamel products with full color and heavy texture.

④ Strength and durability: the thinner metal base material has lower strength and is prone to deformation in the firing process, especially at high temperatures, which may lead to warping or rupture of the carcass; moreover, products with thinner dimensions are less resistant to impact and abrasion, and are easily damaged in daily use, and the thicker metal base has higher strength, which is able to withstand better the thermal stress and mechanical stress in the firing process, and the products are more sturdy and durable It is suitable for the production of enamel products that require higher strength.

Conclusions
In this study, through experiments to evaluate the combination effect of using 3D printing brass, white copper, purple copper three kinds of metal materials and glaze, found that the purple copper and enamel glaze combination is good, adhesion is tight, glaze without shedding, no cracking, no air holes, firing effect is better, purple copper material is suitable for enameling process, can be used as enamel jewelry metal substrate material, and white copper, brass can't be tightly bonded with enamel glaze, when the glaze is cooled down , the glaze naturally falls off and crumbles, and can't adhere to the white copper and brass metal

substrate, so the experiment proves that white copper and brass are not suitable for the production of enamel jewelry and enamel crafts.

The research proves that the combination of 3D printing metal substrate and enamel glaze firing is feasible, greatly improving the production efficiency of enamel jewelry, design freedom, shortening the production cycle, combining 3D printing technology with traditional enamel craft, promoting interdisciplinary research in material science, design and manufacturing process, promoting technological innovation and industry development, and providing new ideas for the modernization of traditional crafts.

Research Contributions

The first, combine 3D printing with traditional enamel craft, establish a standardization framework and firing database, provide theoretical basis and data support for enamel jewelry design, production and standardization.The second, combination of 3D printed metal substrate and enamel glaze is feasible, Experiments confirm that titanium and stainless steel combine well, establish a firing database, optimize the firing parameters of purple copper, promote standardized production, and improve the quality and consistency of enamel jewelry.

References

Wang, Y. X., Wang, Z. Y., Li, M. Z., & Peng, J. R. (2024). *Research on the application of cloisonné enamel craftsmanship in the design of cultural and creative derivatives*. *Ceramic Science and Art, 6*, 70-71. https://doi.org/10.13212/j.cnki.csa.2024.06.103

Shao, H. E. (2024). *The innovative integration of traditional Chinese painting techniques and hand-painted enamel jewelry design*. *Shanghai Vision, 1*, 71-75.

Zhao, H. B. (2023). *Research on the innovative design and application of cloisonné patterns in the Ming and Qing dynasties* (Master's thesis, Xijing University). https://doi.org/10.27831/d.cnki.gxjxy.2023.000178

Duan, Y. L. (2023). *Research on metal enamel base, glaze, and firing process* (Doctoral dissertation, China Academy of Art). https://doi.org/10.27626/d.cnki.gzmsc.2023.000009

Xie, Y. (2024). *Research on the cloisonné enamel craftsmanship in the Qing Qianlong court* (Master's thesis, Hebei University). https://doi.org/10.27103/d.cnki.ghebu.2024.002180

Wang, X. (2023). *Application and research of engraved enamel craftsmanship in jewelry design* (Master's thesis, Luxun Academy of Fine Arts). https://doi.org/10.27217/d.cnki.glxmc.2023.000009

Xiao, J. (2023). *Research on the application of natural elements in enamel jewelry* (Master's thesis, Luxun Academy of Fine Arts). https://doi.org/10.27217/d.cnki.glxmc.2023.000136

Wang, Y. N. (2023). *Research on the innovation and application of glaze effects in enamel jewelry* (Master's thesis, Beijing Institute of Fashion Technology). https://doi.org/10.26932/d.cnki.gbjfc.2023.000034

Tang, Y. (2022). *Research on the application of painted enamel craftsmanship in jewelry design* (Master's thesis, Luxun Academy of Fine Arts). https://doi.org/10.27217/d.cnki.glxmc.2022.000085

Chen, Y. X. (2022). *Application and research of enamel surface effects in contemporary jewelry* (Master's thesis, Luxun Academy of Fine Arts). https://doi.org/10.27217/d.cnki.glxmc.2022.000072

Roberts, D. C., & Green, M. J. (2023). 3D printing and the evolution of jewelry manufacturing: A technological perspective. *Technology in Society, 64*, 101-112. https://doi.org/10.1016/j.techsoc.2023.101112

Liu, Y. (2023). *Construction of microstructures on 3D printed titanium implants and their osteogenic performance* (Master's thesis, Liaoning University of Science and Technology). https://doi.org/10.26923/d.cnki.gasgc.2023.000660

Ma, Y. T. (2022). *Fundamental research on the preparation process of 3D printed silicon-based ceramic cores* (Master's thesis, Academy of Mechanical Science Research Institute). https://doi.org/10.27161/d.cnki.gshcs.2022.000040

Liu, J. F. (2022). *Research on 3D printing fabrication methods for variable stiffness components using low-melting-point alloys* (Master's thesis, Beijing University of Chemical Technology). https://doi.org/10.26939/d.cnki.gbhgu.2022.001765

Zuo, S. N. (2023). *Design and texture control of porous sand molds based on 3D printing* (Master's thesis, Harbin University of Science and Technology). https://doi.org/10.27063/d.cnki.ghlgu.2023.000914

Zhang, Z. (2020). *Research on the creation of enamel works in the style of Ukiyo-e landscape painting* (Master's thesis, Beijing Institute of Fashion Technology). https://doi.org/10.26932/dcnki.gbjfc.2020.000173

Hu, W., Chen, F., & Liao, Q. (2022). Research on marketing strategy of wire enamel process. *Art Market, (08)*, 75–77.

Tang, Y. (2022). *Painted enamel craft application in jewelry design research* (Master's thesis, Lu Xun Academy of Fine Arts). https://doi.org/10.27217/dcnki.glxmc.2022.000085

Liu, Y. (2022). The development and application of enamel technology in contemporary environmental decoration. *Tiangong, (06)*, 64–65.

Feng, T. (2022). Initial discussion on the enamel process and historical evolution of copper tire wire cutting. *Collector, (02)*, 91–96.

Li, Q. (2022). Discussion on the application of enamel technology in jewelry design. *Art Appreciation, (02)*, 59–61.