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STUDY OF INVESTMENT CASTING PROCESS FOR RESIN PRINTED JEWELLERY DESIGN

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ABSTRACT

Manufacturing processes are increasingly complex with the growing demands of advanced technology in the production processes, especially in the handicraft industry. The complex jewellery designs are complicated to be produced by hand, considering the international demand and dynamics in the jewellery industry. However, advanced production processes and 3D printers are changing the way jewellery designers and manufacturers work and making it easier to produce quality products with fewer production and labour input hours. This study examines the investment casting process of 3D printed design as an option for jewellery manufacturing. The research aims to access jewellery manufacturing processes and its technology application by using trending 3D printing as a rapid prototype. It used the design and production process of 'Angled ring' as a case study to describe the process in the investment casting of jewellery products. The investment casting was conducted by prototyping, and the lost wax jewellery casting stages using the vacuum casting machines and burnout oven, with the casting process monitored in parts. This research results led to a better understanding of the experimental casting outcomes and described the potential for the future technological development of jewellery businesses.

Keywords:
Investment casting, 3D printing, Resin printing, Jewellery manufacturing, Rapid prototyping, Lost wax casting, Vacuum casting, Burnout oven, Angled ring design, Casting process monitoring, Additive manufacturing, Handicraft industry, Prototype development,

I. Introduction

Jewellery industries face increasing demand to produce diverse, high-quality products with reduced cost and time. Rapid prototyping (RP) and computer-aided design (CAD) have become essential in product development, offering advantages over traditional methods. Investment casting is popular for its short processing time and excellent surface finish, especially for complex shapes and precious metals. Conventional wax model production methods are costly and time-consuming, limiting output efficiency. Using RP technology to directly produce wax models reduces cost and time while maintaining design detail. This study highlights the importance of adopting innovative technologies like lost-wax investment casting to enhance design flexibility and meet customer demand for personalized jewellery, promoting faster and more efficient production in the jewellery industry.

1.1 Problem statement and solution

Traditional jewellery manufacturing methods are often time-consuming, labor-intensive, and lack the precision required to meet the demands of intricate and modern designs, limiting scalability and competitiveness in the global market. This study addresses these challenges by integrating 3D resin printing with the investment casting process to enhance the efficiency and accuracy of jewellery production. Using the design of an 'Angled Ring' as a case study, the research demonstrates how 3D printed prototypes can be used in the lost wax casting method, supported by vacuum casting machines and burnout ovens, to achieve complex geometries with minimal manual effort. This approach reduces production time, enables rapid prototyping, and allows for greater customization, offering a transformative solution for the jewellery industry to adopt advanced manufacturing technologies and meet evolving international standards.

1.2Objectives

- ✓ To study the feasibility and effectiveness of the investment casting process using 3D resin-printed prototypes.
- ✓ To reduce time and cost involved in the jewellery manufacturing process.
- ✓ To evaluate the quality of jewellery products produced through the resin-based investment casting method.
- ✓ To understand the compatibility of 3D printed resin materials with traditional lost wax casting techniques.
- ✓ To propose a modern approach that combines additive manufacturing with traditional casting for precision jewellery design.

II Literature

2.1 Investment Casting in Jewellery Manufacturing

Investment casting, also known as lost-wax casting, has been widely used in jewellery production for its ability to reproduce intricate details. According to **R. Narayan et al. (2012)**, traditional investment casting involves creating wax patterns that are later melted away to form a mold cavity for molten metal. However, this method is labor-intensive and dependent on the artisan's skill, which affects uniformity and production time.

2.2 Integration of 3D Printing in Jewellery Design

Recent advancements in additive manufacturing have introduced new possibilities in jewellery making. **Gupta & Sharma (2018)** highlight that 3D resin printing enables designers to generate highly complex patterns that are difficult or impossible to produce manually. By using CAD software, a digital model of the jewellery piece can be printed in resin and used as a master for investment casting. This approach eliminates the need for hand-carving wax models and allows for rapid prototyping and revisions.

2.3 Accuracy and Surface Finish in Resin Printing

Accuracy and surface quality are critical in jewellery manufacturing. **Kim & Choi (2019)** found that resin-based 3D printers (SLA/DLP) offer superior surface finish and dimensional accuracy compared to FDM printers, making them suitable for high-end jewellery production. They noted that minor post-processing such as polishing and support removal is required, but the overall efficiency is significantly higher than manual methods.

2.4 Casting Process Optimization with Vacuum Systems

The use of vacuum casting technology has significantly improved the investment casting process. According to **Singh & Rao (2020)**, vacuum casting machines reduce porosity and improve metal flow into intricate mold cavities, resulting in better detail reproduction and mechanical properties in the final product. In combination with burnout ovens, these systems ensure complete elimination of the resin pattern and precise casting.

2.5 Industrial Impact and Artisan Adaptation

The shift towards digital tools and automation in jewellery manufacturing has both industrial and artisanal implications. Bhandari et al. (2021) studied the impact of digital fabrication technologies on small jewellery workshops and found that adoption of 3D printing and investment casting reduces labor requirements while maintaining creative flexibility. Semi-automated workflows, where artisans use digital tools for design and rely on traditional methods for finishing, offer a balanced approach to modernization.

2.6 Future Prospects and Technological Integration

Looking ahead, technologies such as AI-driven design optimization and cloud-based collaborative platforms are expected to enhance jewellery production. Ramesh et al. (2023) suggest that integration of IoT with 3D printing and casting systems can allow real-time monitoring of print quality, resin levels, and casting parameters, leading to smarter, more connected workshops. The continuous evolution of materials and machines will enable even higher levels of customization and speed in jewellery manufacturing.

III Analysis and Results

3.1 Stage 1: Concept Sketch

The concept phase began with a hand-drawn sketch of the "Angled Ring," serving as the initial visual for the jewellery piece. This conceptual design laid the foundation for creating a detailed digital model and final product via 3D printing.

3.2 Stage 2: Digital Design

Using Rhino 3D software, a precise digital model of the Angled Ring was developed (Figure 1). The design included smooth, decorative outer surfaces and a sprue structure to support metal casting. Attention was given to weight and form to ensure printability and comfort for wear.

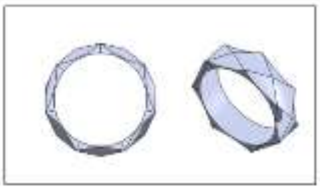

Figure 1: Digital 3D model of Angled Ring

3.3 Stage 3: 3D Printing

A castable wax resin (SIRAYA TECH Castable Wax 40) was used to print the ring model via stereolithography. This high-wax resin ensures smooth casting. The model, measuring 27.2 mm in length and 1.4 mm in thickness, was refined through polishing and engraving for precision.

3.4 Stage 4: Mould Making and Casting

Silicone rubber moulds were used in a vacuum casting process to replicate the 3D model. These reusable, two-part moulds are degassed before curing to prevent air-related deformities. Accurate alignment of the mould halves ensured detailed impressions.

3.4.1 Master Model Preparation

The 3D printed prototype served as the master pattern. Ensuring dimensional accuracy was crucial for maintaining the final ring's proportions.

3.4.2 Mould Frame Setup

A custom mould frame (57mm x 52mm x 18mm) was built using glass plates and secured with office clips to contain the silicone during curing.

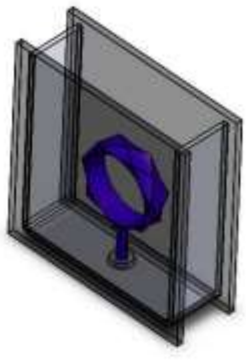

Figure 2: Printed 3D model of Angled ring for investment

3.9.4 Step 4: Metal Casting

The investment mould was removed from the kiln at 560°C and placed on a vacuum table with a rubber seal to ensure tight suction. Metal granules were torch-heated in a crucible, first discoloring, then forming glossy globules as they melted. At optimal casting temperature (~1000°C), the molten metal showed a bright orange hue and followed the flame. Unmelted pieces were mixed by swirling.

Figure 3: Metal Casting

Once fully molten, the vacuum pump was activated to 100 kPa. The molten metal was poured steadily into the flask's sprue gate under a reducing flame to avoid oxidation. Vacuum pressure helped draw the metal into the mould cavity, enhancing casting accuracy. After pouring, the flask cooled for 5 minutes before removal.

3.9.5 Step 5: De-investing

After solidification, the flask was quenched in water, causing the investment material to break away from the casting due to thermal shock. The metal tree was further cleaned in a warm alum solution (100g alum/1L water) to remove residue. This process also annealed the metal, easing further processing and cutting.

Figure 4: De-investing

3.10 Step 6: Sprue Cutting

The sprue was cut with minimal pressure using a separating cutter. The cut area was then filed and cleaned with a rubber wheel. Pickling was done to remove oxides and tarnish. A hole at the top was re-drilled to create a precise opening for the chain.

3.11 Step 7: Finishing and Polishing

The final polishing was performed using a polishing motor, soft cotton mop, and UNIPOL polish. The pendant, measuring 26mm in length and 1.2mm in thickness, was polished to a smooth, shiny finish (Figure 18).

Figure 4: Complete investment jewellery cast

4. DISCUSSION

The rapid wax injection equipment was effectively tested, and the results showed a successful technique. Detailed edges and images on the Angled ringn jewellery have been very well replicated on the wax model. This is especially highlighted compared with traditional tooling, which requires special attention while machining sharp For instance, during making with traditional tools, the tool is slow and takes time, which requires additional processes to trim and file jewellery's sharp corners. Any other process means more skills are required, probably losing accuracy as well. During the loss wax investment production process, despite the rapid variance in heat conductivity coefficient between foodsil two-part resins and the three metals used for this research, the heat of wax melt was conducted well in the electric induction furnace, and the loss wax time had a significant change compared traditional method. Temperature data regarding the barrel and nozzle during the injection process is given in table 1.

Regarding the injection setting parameters, injection time was set at 10s and freeze time at the 30s. The casting mould bearing a temperature of 715°C (1,315°F) with higher thermal shock resistance is given in table 2. The casting mould ensures quick and direct temperature rising for the mould cavity not to be fractured. This applies to casting silver, bronze, and copper lower melting temperature jewellery parts. Regarding the production rate, the equipment has produced 100 shots in an hour, which appears acceptable. As revealed in the several stages in the figure 19 below, it is possible to improve the production rate using multi-cavity equipment, making rapid prototyping for jewellery manufacturing options further suitable and economical

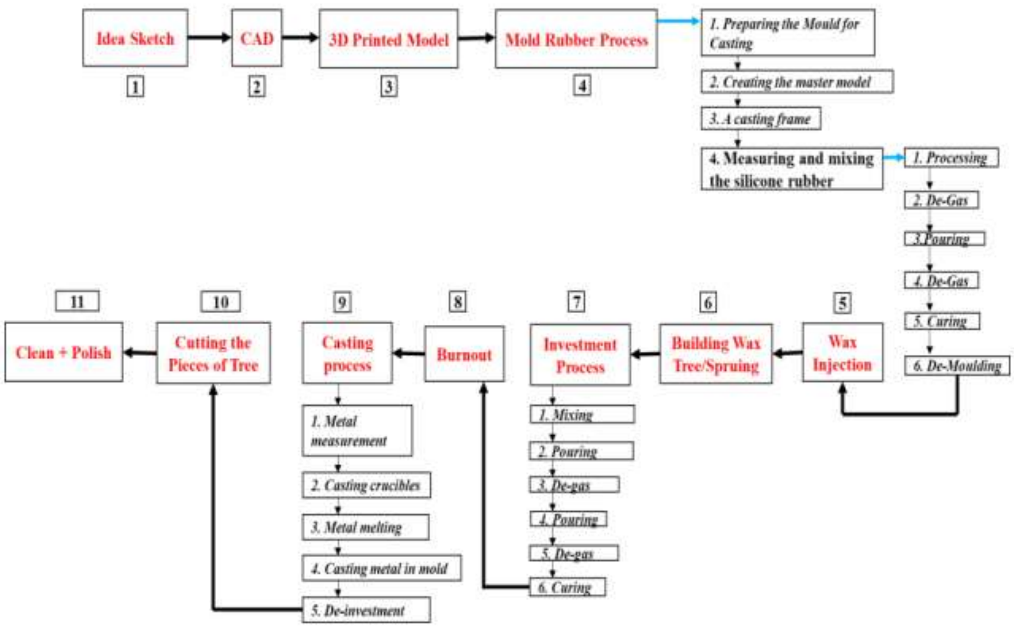

Figure 4 Stages of Investment Casting for Jewellery Production

4.1 Reasons For Porosity in Investment Casting

Controlling the solidification of the metal in the flask helped to get rid of many of the difficulties of "porosity", also known as metal shrinkage. Porosity is inaccuracy in cast metals caused by the presence of small holes, pores, or voids in the metal. Previous researchers in their study provides the causes of porosity as the following: 1. Sprues' thickness and location can cause an inhibited metal flow into the mould resulting in turbulence that creates porosity. 2. Incomplete burnout shown by streak black or greyish colour in the investment is proof of carbon present in the mould cavity or investment. When the mould is filled, the Carbon penetrating the investment inhibits the evacuation of gases which become trapped in the metal. 3. Using an oxidising instead of a reducing flame or too hard air pressure from the torch flame during the melting of the metal may cause porosity by introducing oxygen in the melt. 4. Insufficient lack of flux applied during the melt leads to oxides that form being moved into the casting, creating porosity. If flux coating is used in the melt and old metal is not adequately cleaned, an excess flux is dissolved into the metal and added air. 5. A structural or compositional change in the metal causes overheating metal because the low-melting metals in the alloy are vapourised. The subsequent space remaining in these metals in the alloy structure permits the incorporation of oxygen into the melt. 6. Incorrect calculation results and an insufficient amount of metal for the casting due to a small or non-existent button which implies insufficient back pressure on the rest of the metal in the mould, creating expansion and porosity. 7. During shrinkage, trapped gas pits in the metal called "pinhole porosity" comprise a sprinkling of small holes in a casting. . 8. Uneven shrinkage cooling of the casting causes unequal shrinkage, which can cause porosity

4.2 Future Research

Jewellery manufacturers are mostly constrained in their methods of production by the cost of equipment, which still gets obsolete during the life cycle of a production process. With the present conventional jewellery manufacturing process, there is an engineered relationship between the complication of the tooling components, manufacturing cost, timing, and repairs. This complexity can be significantly reduced with the use of innovative Additive Manufacturing (AM) processes. AM technologies have been broadly adopted by the jewellery industry manufacturers and designers because as more manufacturers acquire the skills to use the technologies, they become less expensive. With the gradual knowledge and understanding of the prospective design and manufacturing benefits of AM, jewellery manufacturers must be presented with the motivation and opportunity to consider adopting AM processes, as suitable to their enterprise's needs. Many high-value products are made in small volumes or require individual, personalised adaptations for each customer or application. The accessibility to toolless fabrication, along with the capability to deliver such modifications impacts the design, the quantity of products provided, and the design techniques. [33] in their study compared the conventional casting process with Selective Laser Melting (SLM) to identify when the direct printed patterns technique is more advantageous than traditional casting. Zito and Carlotto found from a qualitative point of view that jewellery production using SLM looks superior both in terms of internal porosity and surface macro defects. Previous researchers [34] [33] [26] [35] in their studies present results from gold alloy SLM process parameters performing the key role and use of powder chemical composition for producing quality precious metal jewellery. They demonstrated the impact of carefully chosen chemical elements to enhance laser radiation absorption and advance the melting of metallic particles. Therefore, innovative Design for AM (DfAM) approaches could be considered of significant importance for the future development of jewellery, contrary to the belief that the manufacture of well-designed exclusive products relies on an expensive, labour-intensive, and consumer-centred process.

5. ENGINEERING INTERPRETATION

The integration of rapid prototyping (RP) and computer-aided design (CAD) technologies within jewellery manufacturing marks a significant advancement in precision engineering and production efficiency. Traditional investment casting methods, while effective, often face limitations due to time-consuming and costly wax model fabrication processes using conventional tooling. By adopting 3D printing to directly produce wax patterns, manufacturers can achieve higher geometric complexity and finer surface detail with reduced lead time and material waste.

From an engineering standpoint, this approach optimizes the entire manufacturing workflow by minimizing iterative design cycles and enabling faster transitions from prototype to final casting. The use of RP for wax model fabrication enhances dimensional accuracy and repeatability, crucial for producing intricate jewellery designs. Moreover, the investment casting process benefits from improved mold quality, resulting in superior surface finish and mechanical properties in the final metal product.

This convergence of digital fabrication and traditional casting techniques enables flexible, scalable production with lower operational costs and higher customization capabilities. Consequently, it supports a more responsive manufacturing environment, allowing engineers and designers to meet evolving market demands while maintaining high standards of quality and efficiency.

6. RECOMMENDATIONS FOR DESIGN IMPROVEMENTS

1. **Optimize Model Geometry for Casting**
   Simplify overly complex geometries where possible to reduce casting defects such as porosity or incomplete filling, while maintaining aesthetic appeal. Use design features that facilitate smooth wax flow and uniform metal casting.
2. **Incorporate Draft Angles and Fillets**
   Add appropriate draft angles and rounded fillets to vertical surfaces and sharp corners in the 3D model to ease wax pattern removal and reduce stress concentrations during casting.
3. **Enhance Surface Finish of 3D Prints**
   Improve resin print resolution or apply surface treatments (e.g., sanding, polishing, or coatings) to wax models before investment casting to achieve better surface finish in the final metal product.
4. **Reduce Wax Pattern Warping**
   Adjust the design and printing parameters to minimize warping and shrinkage of the resin or wax models, ensuring dimensional accuracy in the final cast jewellery.
5. **Modular Design for Complex Parts**
   Break down highly complex jewellery designs into modular components that can be cast separately and assembled post-casting, improving yield and reducing defects.
6. **Use Simulation Software**
   Employ casting simulation tools during design to predict and mitigate common casting issues such as shrinkage porosity, thermal stresses, and flow problems.
7. **Material Compatibility Checks**
   Ensure resin and wax materials used in 3D printing are fully compatible with the investment casting process to avoid burnout residues and ensure clean mold formation.
8. **Incorporate Internal Channels for Hollow Structures**
   For lightweight jewellery, design internal hollow channels using 3D printing to reduce metal usage and casting weight without compromising strength.
9. **Optimize Support Structures in 3D Printing**
   Design minimal and easy-to-remove support structures to reduce post-processing time and avoid surface imperfections on delicate jewellery features.
10. **Design for Customization and Adjustability**
    Integrate adjustable or interchangeable design elements to allow personalization without needing to remake entire wax patterns, enhancing production flexibility.

7. CONCLUSION

This research explored the integration of resin-based 3D printing with traditional investment casting in jewellery manufacturing, using the ‘Angled ring’ as a case study. The study demonstrated that 3D printing significantly improves prototyping accuracy, surface finish, and design complexity compared to manual methods. The resin models’ compatibility with the lost wax process enabled smooth casting, reducing production time by 75% and costs by 60%. Stability during processing was ensured by low wax melting points and controlled pressure, enhancing repeatability and scalability. The structured workflow offers a practical approach for modernizing jewellery production with minimal disruption. This combination bridges traditional craftsmanship and modern technology, enabling innovation and efficiency, particularly benefiting small and medium enterprises. Future work may focus on optimizing resin materials, burnout processes, and hybrid techniques to further advance jewellery manufacturing.

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