Research on mixture of PES/CaCO₃ as 3D printing materials in restoring ancient architectural works in Vietnam

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Abstract. In this study, we have used selective laser sintering (SLS) 3D printing technology with printing material is a mixture of Polyether sulphone resin (PES)/CaCO₃ powder to recover the stylized dragon, lion, phoenix motifs and ancient works in Vietnam. The experiment has created a 3D product of lion mascot, with the result of mechanical properties tensile strength, flexural strength and impact strength average values, which are 8.08 MPa, 15.28 MPa and 3.09 KJ/m², respectively. Experimental results show that the mixture of PES / CaCO₃ powder is suitable for 3D printing materials in recovering the details and ancient works in Vietnam.

1. Introduction
Currently in Vietnam, ancient architectural works are considered a treasure to be preservation and conservation. However, over a long period of time, due to weathering time, even due to human impact, some parts, reliefs and textures are damaged. Most of the ancient architectural works in Vietnam, stylized dragon and phoenix motifs are partially broken or completely broken (marked position) (Figure 1); Most of the statues of some dragon, lions in the pagoda gate, gates of ancient architectural works weathered weather, lost some parts (at the positions marked with circles) (Figure 2). Therefore, the restoration and repair are urgent jobs today.

Figure 1. Pagoda gate in Quang Tri province  Figure 2. Lions are broken some parts
According to survey results, these ancient architectural works were repaired partly to meet the wishes of the Vietnamese people. However, with the current method of making manuals, it takes effort and does not create complicated patterns that require high art. So it is necessary to find a new technology to meet this practical requirement.

In fact, ancient architectural works in Vietnam were built with 50 ÷ 60% natural materials such as stone, brick and cement remaining made of natural wood. More specifically, the location and installation space of these pattern patterns are outdoors so often exposed to sun and rain. Therefore, finding the original material-like materials of ancient buildings has the ability to weather and anti-aging weather is an urgent task to be studied.

Laser sintering is a laser based rapid manufacturing technique that builds objects layer by layer from powders through computer-aided design (CAD) technology. There are various laser fabrication processes such as directed-light fabrication (DLF) [1], laser engineered net shaping (LENS) [2], direct metal deposition (DMD) [3, 4], selective laser sintering (SLS) [5, 6] etc. These techniques incorporate features from stereolithography and laser surface engineering, using a CAD model to control the sequentially thin-layered forming process. SLS technology is a 3D printing technology. Unlike other 3D printing technologies, in the SLS process there is a wide material selection, no support is needed during manufacturing, and unsintered material could be recycled and reused [7]. Therefore, SLS has been widely applied in industries [8, 9].

From the urgent need to repair the ancient architectural works and samples presented above, through the time of researching on SLS 3D printing technology, we have selected the mixed Polyether sulphone resin (PES) / Limestone flour (CaCO₃) research as 3D printing material. With the goal of creating 3D printing materials suitable for restoring ancient architectural works in Vietnam

2. Materials and methods

2.1. Material
In this study using Polyether sulphone resin powder (PES), and limestone flour (CaCO₃) supplied by the company Shanghai Tian Nian Materials Technology Ltd (Figure 3). Before the limestone flour powder was mixed with PES it was dried at 55°C for 8h.

![Polyether Sulphone Resin(PES) and Limestone Flour(CaCO₃)](image)

**Figure 3.** Polyether sulphone resin and limestone flour powder

2.2. Laser sintering experiment
Selective laser sintering (SLS) experiments were performed using an AFS360 rapid prototyping machine fabricated by Long yuan AFS Co., Ltd. Based on preliminary results, the bed temperatures of PES mixtures with CaCO₃ powder were all set at 80 - 90°C. The process parameters were laser power 12 W, cross-scan speed 2.0 mm/s, scan spacing 0.2 mm and layer thickness 0.1mm (Figure 4)
2.3. Mechanical testing
Mechanical testing was performed on a CMT5504 testing machine from TMS System Company and a TCJ-4 impact touching screen testing machine with simply a supported beam produced by the Tai He Testing Machine Limited, Jilin Province. The test standards are as follows:

Dog bone-shaped tensile specimens with typical dimension of 166x13x3.2 mm were fabricated. The crosshead speed was 5 mm/min according to ASTM D638-10. For flexural strength, thin specimens of 127x12.7x3.2 mm were tested according to the three-point bending method of ASTM D790-10. The support span was 52 mm, crosshead speed was 2 mm/min and maximum midspan deflection was 15mm. A digital Charpy impact tester was used to measure normal impact strength of unnotched specimens (80x10 x 4 mm) based on ISO 179-1.

3. Results and discussion

3.1. Print simulation of specimens
There are at least two methods to perform 3D printing: Method 1 use a 3D camera to take pictures and then put data into specialized design software; Method 2 use 3D design software to draw specimens, then put data into 2 software, Magics 15.1 and ARPS 701. In the article we used the second method to draw 3D specimen as shown in (Figure 5)

The mixture of PES and CaCO3 materials is weighed in a reasonable proportion, then both types of powder are mixed by specialized machines. The powder mixture is mixed into the printer tray and proceeded to 3D printing. After the printing process, the sample of the Lion mascot has been printed.
and shown in (Figure 6). From (Figure 6) shows that the Lion mascot model has a very complex shape. If using a traditional method to create this product, it must be done within 4 to 7 days. However, with the 3D Selective Laser Sintering (SLS) method that we have done, it only takes 6 hours. The printed specimen results show that the shape and size of the printed specimen are exactly with the same as of the design. The color of the Lion mascot is very uniform, the bonding of the two materials together is very good.

The results show that this 3D printing technology has succeeded in printing specimens with complex shapes at a rapid rate. This technology will help in restoring ancient architectural works in Vietnam. Specifically, the mixture of PES/CaCO3 materials as 3D printing materials during the restoration of ancient architectural works in Vietnam will save time and save costs.

3.2. Mechanical property analysis

Table 1 show that the experimental program of full factorial design and results of tensile strength, bending strength, and impact strength. Experimental results shown in Table 1 indicate that when the laser power is 12W, scan speed 2 m/s, scan spacing 0.2 mm, then tensile strength, flexural strength and impact strength average values, which are 8.08 MPa, 15.28 MPa and 3.09 KJ/m2, respectively.

| No | Laser power (W) | Factors | Scan speed (m/s) | Scan spacing (mm) | Tensile strength (MPa) | Bending strength (MPa) | Impact strength (KJ/m²) |
|----|----------------|---------|-----------------|------------------|-----------------------|----------------------|------------------------|
| 1  | 12             | 2       | 2               | 0.2              | 8.12                  | 15.22                | 3.746                  |
| 2  | 12             | 2       | 2               | 0.2              | 8.16                  | 15.24                | 4.025                  |
| 3  | 12             | 2       | 2               | 0.2              | 7.98                  | 15.39                | 3.945                  |
|    | Average        |         |                 |                  | 8.08                  | 15.28                | 3.905                  |

The results show that the mechanical properties of printing materials are relatively good. Compared with some other authors' studies on 3D printing materials, Huang ET, al (2018) reported the tensile strength, flexural strength and impact strength average values, which are 3.46 MPa, 6.320 MPa and 0.61 KJ/m², respectively. So the mechanical properties of the selected materials in this study are higher than 2.32, 2.34, 6.34 times, which are tensile strength, flexural strength and impact strength average values, respectively. The results of mechanical properties show that the selected 3D printing materials PES/CaCO3 have appropriate mechanical properties to make printing materials to restore ancient architectural works in Vietnam.

4. Conclusion

1. The study has used selective laser sintering (SLS) 3D printing technology with printing materials as a mixture of PES/CaCO3. The results show that the experiment has successfully printed a complex lion mascot with fast printing time, and ensuring the mechanical properties of materials suitable for the products to be restored.
2. Based on the results of this research can be applied to research into the production and restoration of the mascot statue, pattern motifs in ancient architectural works in Vietnam.
3. The result of this study is a scientific basis for businesses that want to develop and produce complex mascot objects in the direction of industry. At the same time it is also a scientific basis for other scientists to consult to develop other types of 3D printing materials.
4. The study was successful in creating 3D printing materials with PES/CaCO3 powder. However, in order to enhance the application of this printing material, the future needs to have researches to determine the optimal ratio of PES / CaCO3, and it is necessary to study the weather aging test of materials to Application expansion of printed products.
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