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Effect of Infiltrating Action on the Mechanic Property for 3DP Technology

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Abstract:

Three-Dimension Printing(3DP) technology integrates computer aided design and manufacturing (CAD, CAM), automatic control technology and digital printing technology. The ink with bonding function contained in the nozzle is used as the binder, which is sprayed on the medium powder as needed to bond and form, and is widely used. The precise forming of inorganic powders such as gypsum can be realized by 3DP technology, but the mechanical properties of the technology are poor due to many factors. The infiltrating action in the reprocessing process is considered as the research object, the effects of infiltration times, infiltration modes, and infiltration interval on mechanical properties are explored by the compressive strength, SEM, and EDS, where the compressive strength is measured by materials testing machine. The experimental results show that the mechanical properties of the formed parts can be effectively improved by multiple infiltrations and gradually increasing the infiltration interval. The research results provide a reference for the infiltration action of post-treatment of 3DP formed inorganic powder materials.

***Keywords**: 3DP technology; Reprocessing; Infiltrating; Gypsum powder; Mechanical property.*

I. INTRODUCTION

According to different process forms, Additive Manufacturing (AM) is commonly classified into Fused Deposition Modeling (FDM), Stereo Lithography Apparatus (SLA), Selective Laser Sintering (SLS), 3DP, and so on [1-6]. Among them, the 3DP process can be widely used in the Additive Manufacturing of inorganic powder, with high forming accuracy, but poor mechanical properties hinder the further popularization and application of this process. Many factors affect the mechanical properties [7-8], and there have been many research results. Liu Quan-sheng et al. discussed the effects of drying time, printing glue concentration, and printing direction on the mechanical properties of 3DP formed parts. The results showed that using 175% glue saturation to print the sample and placing it at room temperature for two weeks after printing can obtain higher uniaxial compressive strength. With the increase of printing angle, the strength showed a "U" curve of first increasing and then decreasing [9]. Kathy Lu et al. studied the influence of powder particle size on precision and mechanical properties. The test results showed that the smaller the particle size, the better the mechanical properties of the formed parts [10]. Arghavan Farzadi et

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al. analyzed the impact of printing delay time on printing performance. The higher surface accuracy and greater compressive strength of printed parts could be improved by prolonging the printing time [11]. Mohammad Vaezi et al. analyzed the influence of layer thickness on the 3DP process. With the gradual increase of layer thickness from 0.087mm to 0.1mm, the tensile strength gradually decreased and the flexural strength gradually increased [12]. To sum up, it can be found that previous studies mainly focus on considering the influence of material characteristics and printing process parameters on printing performance, but 3DP process is not only related to the material itself and printing process, but also other important factors, such as post-processing. At present, few scholars have studied the influence of this part. Therefore, the influence of the post-treatment link of infiltration treatment on the mechanical properties of 3DP process parts will be emphatically considered here. The main factors are infiltration times, infiltration modes, and infiltration interval. The changes of pressure resistance under different experimental conditions are discussed from the macro test and microstructure.

II.EXPERIMENTAL PREPARATION

The 3D printer used in the experiment is the ProJet CJP 660 Pro full-color printer produced by 3D systems, as shown in Fig 1. The material used is the recommended supporting material VisiJet PXL composite gypsum powder material, and the penetrant is the recommended liquid material ColorBond, which can not only increase the strength of formed parts, but also improve the brightness of colors.

The experimental sample is a standard cylindrical part with a diameter of 30mm and a height of 30mm. The macro test mainly uses the mechanical test platform Instron 3367 as shown in Fig 2 to measure the compressive strength of relevant formed parts, and the microstructure is mainly analyzed by SEM and EDS.

The specific experimental process is as follows:

- Print standard cylindrical parts.
- Carry out preliminary post-treatment, remove the excess gypsum powder on the surface of the formed part and recycle it.
- Penetrant shall be used for treatment, and the treatment requirements of different formed parts shall be implemented according to the contents listed in TABLE I.
- After treatment, the formed parts are naturally air dried and placed for 12 days.
- Test and record the macroscopic mechanical properties, i.e. compressive strength.
- The crushed fragments were scanned and analyzed by SEM and EDS to obtain the information of microstructure and element composition.

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Fig 1: The full color 3D printer of Projet CJP 660 Pro

Fig 2: The mechanical test platform of Instron 3367

TABLE I. Post treatment requirements of formed parts in seven groups of experiments

SERIAL NUMBER	POST-TREATMENT CONTENT
Formed part 1	No infiltration treatment
Formed part 2	Manual penetration of penetrant, once
Formed part 3	Penetrant infiltration, once
Formed part 4	Infiltrate with penetrant twice. The interval is 15 minutes
Formed part 5	Infiltrate with penetrant twice. The interval is 25 minutes

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Formed part 6	Infiltrate with penetrant for 3 times. The interval is 20 minutes
Formed part 7	Infiltrate with penetrant for 3 times. The interval between the first and second times is 15 minutes, and the interval between the second and third times is 25 minutes

III.EFFECT OF INFILTRATION TREATMENT ON MECHANICAL PROPERTIES

Relevant mechanical tests were carried out on the above seven formed parts by using Instron 3367 mechanical test platform. The specific compressive strength results are shown in TABLE II.

TABLE II Test results of compressive strength

SERIAL NUMBER	1	2	3	4	5	6	7
COMPRESSIVE STRENGTH (MPa)	2.12	4.32	4.91	5.39	5.15	5.14	5.52

3.1 Influence of Infiltration Mode

According to the arrangement of the above experiment, the formed parts 2 and 3 are mainly used to analyze the influence of the infiltration mode on the mechanical properties. At present, there are two penetration modes. One is to use a brush to apply the penetrant to the surface of the formed parts, which avoids the waste of penetrant and saves the material cost, such as the formed part 2; Another method is to immerse the formed parts directly into a container containing a large amount of penetrant, such as the formed part 3.

This method can avoid the non-uniformity of manual penetration, and the excess penetrant can still be recycled for recycling. However, in this way, in the actual operation process, due to the viscosity of the penetrant, there will be excess penetrant attached to the surface. To ensure the surface quality, it is often necessary to gently wipe the outer surface with absorbent paper to absorb excess penetrant. The compressive strength of two different infiltration methods are 4.32MPa and 4.91MPa respectively. The infiltration method is better than the manual infiltration, because the manual infiltration can not ensure the uniformity and the penetrant can not effectively infiltrate into the inner of the formed part.

Fig 3 and Fig 4 are SEM images of the outer surface and interior of the two formed parts, respectively. It can be seen from Fig 3 that the surfaces of the two formed parts are in different states. The test sample in Fig 3 (a) just corresponds to the uneven part of the coating. Compared with Fig 3 (b), it is not penetrated and adhered to by the penetrant. As can be seen from Fig 4, the particles in Fig 4 (a) appear looser than Fig 4 (b). The comprehensive microstructure further proves that the infiltrating method is more conducive to obtaining better mechanical properties than the manual penetration method.

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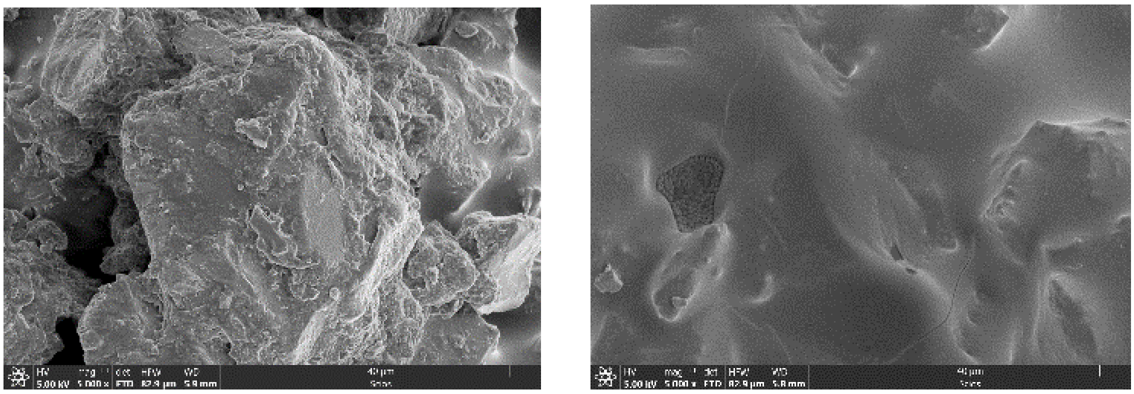
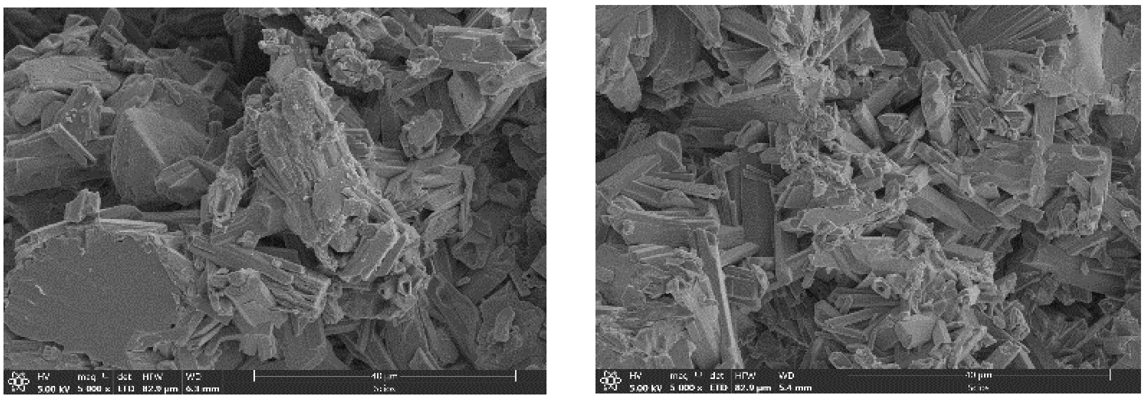


(a) the formed part 2 (b) the formed part 3

Fig 3: SEM of the outer surface of two formed parts



(a) the formed part 2 (b) the formed part 3

Fig 4: SEM of the interior of two formed parts

3.2 Influence of Infiltration Times

According to the above conclusion, the infiltration method is more conducive to obtaining better mechanical properties, so the infiltration method is adopted in the subsequent experiments. When considering the influence of infiltration times on the mechanical properties of formed parts, select formed parts 1, 3, 4, 5, 6, and 7 for comparison, in which the formed part 1 is not subject to post-treatment, that is, the infiltration times are 0. The formed part 3 is penetrated once. The formed parts 4 and 5 are penetrated twice, the infiltration interval is different. The formed parts 6 and 7 are penetrated three times, and the infiltration interval also is different. According to the test results of compressive strength in TABLE II, the compressive strength of the formed part 1 is the smallest, which is obviously due to the small bonding force between powder particles without post-treatment with penetrant. The mechanical properties of the formed part 3 after once infiltration treatment are significantly improved. The compressive strength is further improved when it is further infiltrated two times, but the improvement of the mechanical properties is not very significant after three infiltrations. At this time, the penetrant tends to be "saturated" inside the

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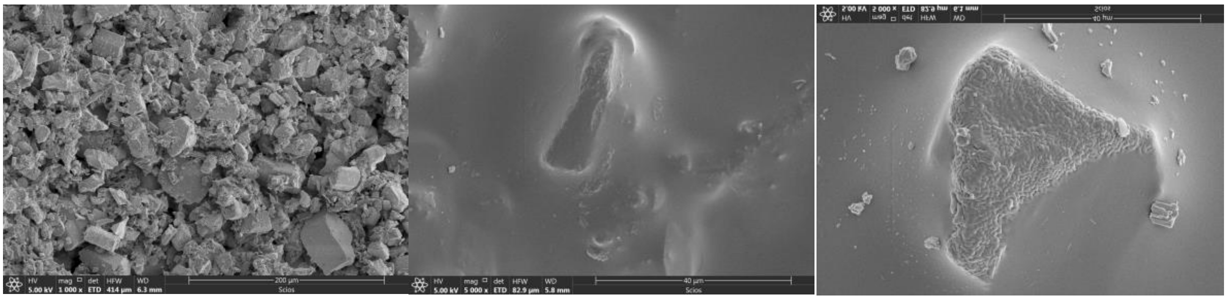
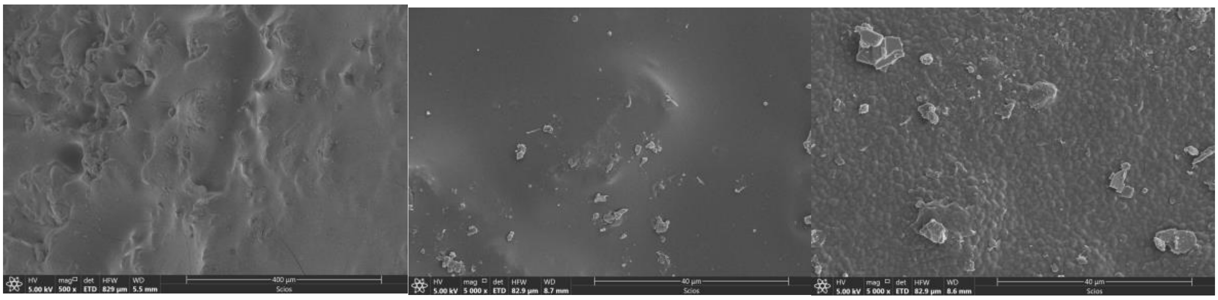
formed part. Therefore, multiple infiltrations within a certain range can help to improve the mechanical properties, beyond a certain range, there is no obvious improvement effect.

Fig 5 and Fig 6 are the SEM images of the outer surface and interior of the above formed parts respectively. Fig 5(a) shows the sense of particles, while the other pictures show the state that the particles are "wrapped" by penetrant.

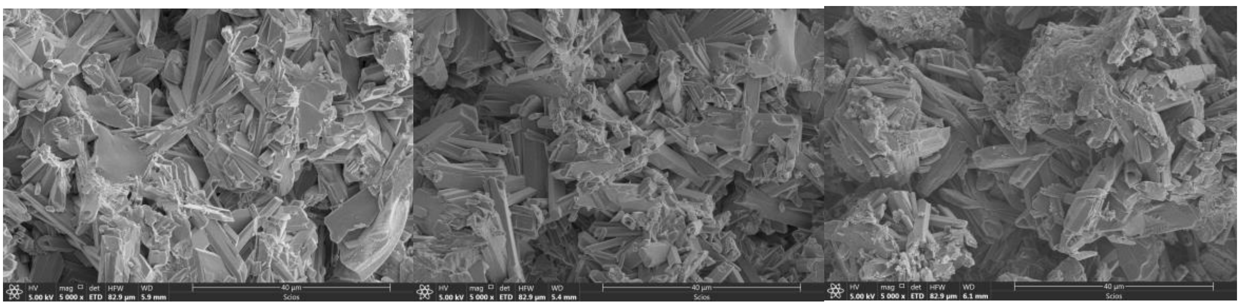


(a) the formed part 1 (b) the formed part 3 (c) the formed part 4



(d) the formed part 5 (e) the formed part 6 (f) the formed part 7

Fig 5: SEM of the outer surface of six formed parts



(a) the formed part 1 (b) the formed part 3 (c) the formed part 4

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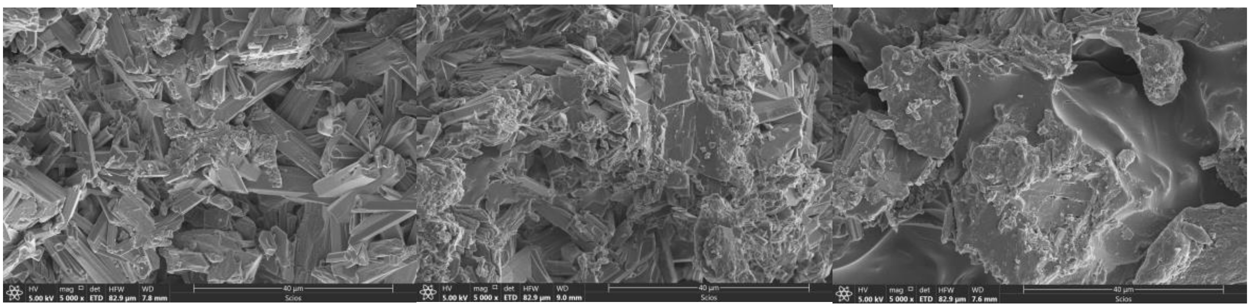

(d) the formed part 5 (e) the formed part 6 (f) the formed part 7

Fig 6: SEM of the interior of six formed parts

3.3 Influence of Infiltration Interval

According to the experimental arrangement, the formed parts 4, 5, 6, and 7 can be used to consider the influence of infiltration interval on mechanical properties. The formed parts 4 and 5 have undergone twice infiltration treatments, and the formed parts 6 and 7 have undergone three times infiltration treatments. Compared with the formed parts 4 and 5, it is found that the infiltration interval of 15 minutes can obtain greater compressive strength. Compared with the formed parts 6 and 7, it is found that the inconsistent infiltration time can make the formed part show better mechanical properties. The SEM images of the above formed parts are shown in Fig 5 and Fig 6. Compared with Fig 5(c) and Fig 5(d), the particles in the former are not completely wrapped. Compared with Fig 6(e) and Fig 6(f), the latter has a larger wrapping range. The above analysis again confirms the results of the mechanical property test.

3.4 Analysis of EDS

The main element in gypsum powder is Ca. During the experiment, the content of the Ca element in the outer surface is detected by EDS and compared with the corresponding mechanical properties. The specific data are shown in Fig 7. According to the comparison results, it can be found that when there are more Ca elements on the surface, the mechanical properties of the corresponding formed parts are poor. At this time, the content of penetrant is less. On the contrary, when the content of the Ca element is less, the content of penetrant is correspondingly more, so that the powder particles are "wrapped", the force between the particles is strengthened, and the mechanical properties of the formed parts are effectively improved.

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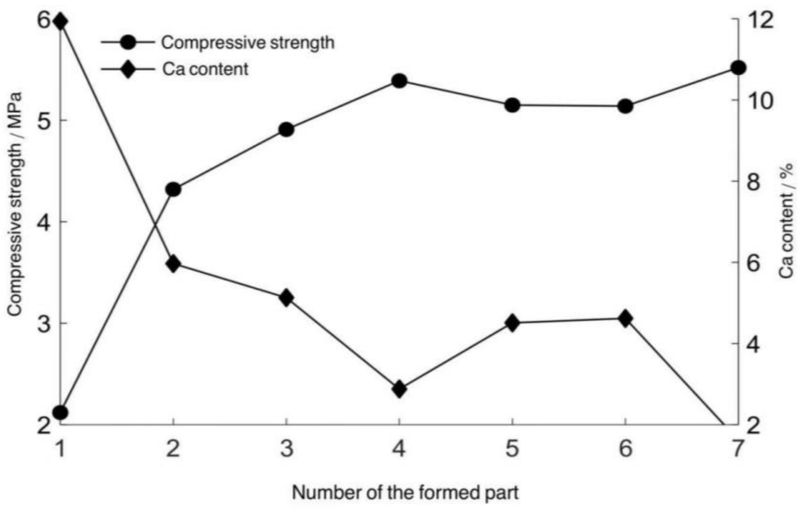

Fig 7: Comparison between compressive strength and Ca content

IV. CONCLUSION

In view of the influence of infiltration treatment on the mechanical properties of the formed parts in the post-treatment link of the 3DP process, the effects of infiltration modes, infiltration times, and infiltration interval on the mechanical properties of the formed parts are considered, and the macro mechanical test, micro SEM and EDS are comprehensively used.

The conclusions are as follows:

- The infiltration modes should be selected. On the one hand, it can ensure the uniform infiltration of the surface. On the other hand, it can make the penetrant fully infiltrate into the interior of the formed part, which is helpful to improve its mechanical properties.

- The infiltration times should be enough within a certain range. According to the experiment, it can be found that the compressive strength of the formed parts in this case increases with the gradual increase of the number of infiltration. If the compressive strength is not significantly improved after 3 times of infiltration, it can be considered that two times of infiltration can meet the experimental requirements.

- The infiltration interval time should not be too long. When there are multiple infiltrations, the interval time of subsequent infiltration should be greater than that of the previous infiltration.

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