# RECLAMATION OF WASTE SAND GENERATED FROM 3D PRINTER

**Harsh H. Upadhyay, Onkar E. Patil, Rasika S. Jadhav, Rutika S. Patil, Divya P. Ulape and Nilesh T. Mohite**
D.Y. Patil College of Engineering and Technology, Kasaba Bawada, Kolhapur 416006, India


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## Abstract

*Three-dimensional (3D) printing is rapidly converging with the foundry industry in the recent years and tends to increase more in upcoming years. 3D printing is largely used for making sand molds and printing process uses sand which is imported. This sand in terms of costing is very high in comparison to Indian sand used in sand metal casting. Thus, waste generated from the printer is not affordable and increases the initial printing cost. To reuse the sand, reclamation is the solution which is effective and will reduce the initial printing cost. As the initial cost decreases printing process can be used for mass production of molds and cores. This paper presents a study of reclamation done on two types of waste sand printed and loose sand. It also suggests a range of temperature for reclamation of both the type of waste sand. Thermal process of reclamation is used as the binder used in the printing process is furan base. As furan binder evaporates at a certain temperature, the sand can be reclaimed and reused.*

***Keywords:*** *3D printing, sand reclamation, thermal reclamation*

## Introduction

According to the "Modern Casting" 2013 World Census of Casting Production, India is the third largest producer of casting in the world with annual production of 10 million metric ton,[1] which in 2019 increased up to 11.49 million metric tons and is expected to expand more with an annual growth of 12.5% till 2023.[2] The metal casting industry is in recovery phase after the crisis in 2008, as the customer demand continues to increase, the sales of all cast metal are increasing too.[3] This growing market shows the scope of new advancements and technologies which can be used in the foundry industry. One of it is 3D printing. 3D printing has been recognized as an efficient and sustainable technology in the fields of advanced manufacturing.[4,5]

3D sand mold printing, as an application of additive manufacturing (AM) in foundry industry and one kind of modern mold manufacturing technologies, is based on the combination of computer-aided design (CAD) and digital control technology to produce sand mold without wooden pattern.[6] Sand mold 3D printing technology is a sophisticated producing technology that has nice versatile producing ability.[7] 3D printing sand mold technology offers a chance for the foundry industry to rethink old casting approaches and to revive the producing approach victimization computer models.[8] Binder jetting involves printing a polymer binder onto a powder bed with a typical inkjet print head to create one cross-sectional layer of the part. The powder bed is lowered after a layer of binder is printed, and fresh powder is deposited over the powder bed with a roller. The next layer of the part is then patterned on top of the preceding layer on the powder bed. The object is built layer by layer in this manner.[9] The 3D printing of sand molds, by binder jetting technology for rapid casting, plays a vital role in providing a better value by producing quality and economic sand molds.[10]

New technologies and developments grow the market and lead to commercial success. Currently, 3D printing has popularly grown in all field of engineering and science, also impacting the foundry industries. Foundry industries are evolving around the world with technologies adding up to speed the production as well as the quality of the casting. 3D printers are introduced in the production of mold making for metal casting by different firms all over world. ASF April 2022 journal mentioned that the adoption of 3D

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printing will continue to accelerate in coming years. The time and knowledge required to make a sand molds design are considerably decreased with additive manufacturing (AM), also known as “3D printing”.[11] The casting products produced from the 3D printed molds require very less post-processes and have high accuracy. Complex geometries which are even difficult to manufacture with CNC can be manufactured by the help of 3D printer. Advantages like ability to produce combine multiple components, usage of less energy and defect optimization have made 3D printer more popular worldwide in foundry sector. Many limitations of sand casting are now overcome due to 3D printing.[12]

Even though 3D printing is additive manufacturing process, it produces 40% of waste sand in single print. Waste foundry sand (WFS) is the by-product of casting industries and is utilized to make molds.[13] This waste sand consists of two types, first is loose sand which is not been printed but still consists of small amount binder and activator in it and second is the core and the test bars printed but which are not the part of mold. The printed sand is grinded for the experiment purpose and appears, whereas loose sand is completely unbounded but as mentioned contains a little amount of binder in it. This waste generation is becoming a drawback for 3D printers. As the sand used in these printers is imported in India, this waste is a huge loss of money and impacts the initial costing of printing. Generally, this waste is directed to dump apart the very fact that main part (70%) is the totally recoverable silica sand which can be used further.[14] This sand is dangerous to environment so dumping is not an option and storage can also be issued for the company. Most of the binders used in the printing process are furan binders, which are hazardous in nature, and thus, dumping of this waste sand becomes more difficult. Furan-based binders are cryogenic, and activator used is acid in nature and is not good for human exposure.[15] In foundry, sand-molding takes most proportion of manufacturing than different molding methods. So, the foundry calls for large amount of sand daily. To protect environmental troubles, it’s miles vital to reuse the sand repeatedly in any other case it additionally will increase disposal cost.[16] Over 70% of all metal castings are produced via a sand-casting process. Sand casting is one of the most popular and simplest types of casting.[17] Due to environmental procedure pointers and to create the method additionally economical, when the casting is made, the oxide sand is recovered by means that of thermal or mechanical reclamation treatments, and then, it is reused in casting production (Rafal Danko et al, 2020**). Thus, reclamation is becoming a necessity in foundry as foundryman cannot afford to continue paying for new sand and for disposal.[18] Sand reclamation is the process of restoring the original condition of molding sand so that it could be reused with minimal fresh sand[19]

There are generally three methods for the recovery of reusable sand from waste foundry sand: thermal reclamation, wet mechanical reclamation and dry mechanical reclamation.[20,21] The wet and thermal sand reclamation achieves acceptable grain size of reclaimed sand. Used sands can be reclaimed as support sand after dry treatment or reconditioning, but for use as fresh sands wet or thermal reclamation is necessary.[22] Thermal reclamation involves heating spent used sands containing resins to a temperature that allows entire or partial combustion of the organic binder. Thermal treatment of wasted used sands containing binders should produce partial or entire destruction of inorganic components of a binder, allowing sand grains to be liberated from burned binder envelopes.[23,24] For organic binders like no-bake binders, thermal sand reclamation technique provides higher results. Thermal process is treating furan binder bounded sand in hot fluidized bed.[25] The thermal reclamation procedure is more expensive than other reclamation processes for wasted molding and core sands, but it provides the best cleansing of mineral matrices from organic binders in the majority of cases.[26] Thermal reclamation approach is specifically aimed for the reclamation of spent sands containing natural binders and, however, is likewise used for the deactivation of additives of sands containing binders in systems, wherein the choice of spent sands is not provided. Certain advantages like correct elimination of binding agent, opportunity of utilization of overall reclaimed sand for the manufacturing of clean molding and center sands and negligible chemical harmfulness of dirt for the environment favors for thermal reclamation.[27]

Reclaiming the sand will decrease the wastage, which in return help to reduce the printing cost. Currently, 3D printers are not used in mass production due to its high initial cost. But if the printing cost is reduced, printers can be used for mass production of molds. An article in Business Today on IIF’s 67th Indian Foundry Congress (IFC) stated that IIF is looking forward to build common reclamation units to reclaim waste sand generated from major foundries. IIF president Shahi said that the used sand will be reused in casting production and the recovery is about 70–80%.

This research work is based on the problem identified at Ghatge Patil Industries (GPI) Ltd., Kolhapur, which is into the foundry industry. Foundry industries using sand 3D printers for molds and core making have a major issue of waste sand generated from these 3D printers. GPI (Ghatge Patil Industry) uses VX4000 Sand 3D printer for prototyping of molds and cores. Each full volume print consists of 40% of waste sand. The sand used in printing process is imported from Germany with higher rates than Indian sand used in foundry processes. Sand cannot be used again for printing; thus, reclamation is a great option for it. Yearly the company generates 192 tons of waste sand, costing 36,48,000 INR. Thus, waste generated from the printer is not affordable and increases the initial printing cost. Thus, the purpose of the current research work is to make the sand reusable using thermal reclamation process so as to reduce high initial printing cost.

This paper presents a detail study on sand reclamation of waste sand generated from 3D printer. Different parameters like particle size distribution (PSD), scanning electron microscope (SEM), grain fineness number (GFN) and visual analysis are experimented to support the results. A range of temperature for reclamation is also suggested

Detail of the printer on which study was carried out is given in Table 1 along with specification.

## Experimentation

In current scenario, reclamation is possible in three different ways— dry mechanical, wet and thermal processes. Mechanical and chemical processes are less effective in terms of results for furan-based binder, whereas thermal process is more convenient and has higher accuracy for reclamation. As the binder used is furan base, thermal reclamation was opted for laboratory-scale experimentations. The process of thermal reclamation was carried out on an electrical laboratory furnace. Table 2 shows the details of number of samples and number of heating tests performed.

***Table 1. Detail of Printer and Its Specifications***

| Item | Details |
|---|---|
| Printer | Voxeljet VX400 |
| Build space | 4000*2000*1000 (L*B*H) |
| Build speed | 300 µm |
| Print resolution | 200 dpi |
| Available process | Sand (Furan) |
| Base material | Raw silica sand of different grain sizes. |
| Binder type | Furan resin |
| Binder composition | Furfuryl alcohol 70–90%, isopropylidendiphenol 10–20%, benzenediol 2.5–3%, aminopropyltriethoxysilane 0.1–1%. |
| Activator | p- toluenesulfonic acid |
| Activator composition | p- toluenesulfonic acid 50–99%, Sulfuric acid 1%. |
| Binding strength | 250–500 N/cm$^2$ |
| Sand | GS19 |
| AFS (GFN) | 66 |
| Sand composition | $Fe_2O_3$ 0.15%, $Al_2O_3$ 0.2%, $Tio_2$ 0.2%, $Sio_2$ 99.1%. |

***Table 2 . No. of Samples and Heating Tests Performed***

| Samples | Heating test's |
|---|---|
| Types of samples | 1. Printed sand |
| | 2. Loose sand (Unprinted) |
| Tests for Printed sand (furnace test in degree Celsius) | 1. 800 |
| | 2. 600 |
| | 3. 400 |
| | 4. 500 |
| | 5. 450 |
| Tests for Loose sand (furnace test degree Celsius) | 1. 800 |
| | 2. 500 |
| | 3. 200 |

### Procedure

1. 110 gm of sample sand is taken in a dish and spread evenly for even exposure of heat.
2. The sample is kept in the electrical laboratory furnace, and temperature is set.
3. Once the temperature is achieved, sample is held for 20 min (Holding period).
4. After that temperature is lowered to room temperature and sample is extracted from the furnace.
5. Sample further is sent for result analysis (PSD, GFN, SEM).

## Results and Discussion

To compare and investigate the parameters of reclaimed sand and fresh sand, five different analyses were done. Table 3 gives all the experimental details performed.

### Visual Analysis

In visual analysis, color comparison of sample sand was performed for optimal match of reclaimed to fresh sand.

#### *Printed*

After heating the samples changed color, as the color of printed sand was black gray. Original color of sand is white in nature as seen the picture below.

*Table 3. Details of Analysis Done After Heating Tests*

| Analysis | Details |
|---|---|
| PSD (Particle size distribution) | Performed on LA-960 Laser Scattering Particle Size Distribution Analyzer. PSD was done to examine the difference in particle size of all samples. |
| GFN (Grain fineness number) | Performed on Sieve Shaker. GFN was calculated to cross examine the GFN of reclaimed sand to fresh sand. |
| SEM (Scanning electron microscope) | Performed on FEI Quanta 200 SEM. SEM was performed for detail microscopic study of sand particles. |
| Visual analysis | Performed visually by observing the color differences |
| Weight loss | Performed by calculating the loss in ignition. |

***Figure 1. Fresh sand.***

Figure1 shows the fresh sand. As the tests were taken first at 800 °C, the color changed and appeared reddish in nature as shown in Figure 2. This visually proves that the sand was overhead and the temperature required for reclamation is exceeding.

As the sand was overheating the temperature was lowered. But at 600 °C too the sand showed a little reddish nature in color. The sample at heated 600 °C is shown in Figure 3.

***Figure 2. Printed sand heated at 800 °C.***

***Figure 3. Printed sand heated at 600 °C.***

This proved that the sand was still exceeding the temperature required to reclaim and was overheated.

Further temperature was decreased again and the sand was heated at 400 °C. At this temperature binder coating of the sand particles does not burn totally leaving back lot of residues. Thus, the color of the sample at this temperature is gray black as shown in Figure 4 and it is clearly states that the binder is still present in the sand. Observing that the binder does not evaporate at 400 °C, now temperature needed to be increased. Next test was taken at 500 °C as the intermediate temperature. Binder at this temperature was seen completely burned and evaporated. The color of the sand after heating at 500 °C resembled with the fresh

*Figure 4. Printed sand heated at 400 °C.*

*Figure 5. Printed sand heated at 500 °C.*

sand which can be seen in the comparison of Figure 5 and Figure 6.

Additionally, a final test was taken as an intermediate temperature of 400 °C and 500 °C. The sample was heated at 450 °C and it was observed that the sand contained few residues of binder. Even if the binder was evaporating at this temperature, it was not completely evaporated. This can be observed in Figure 7.

*Figure 6. Fresh sand.*

*Figure 7. Printed sand heated at 450 °C.*

### *Loose Sand (Unprinted)*

Tests on loose sand showed similar results like printed sand at 800 °C. The color exhibited reddish nature which can be observed in Figure 8 and proves that the sand is overheated.

After observing the binder's behavior with different temperatures in furnace next test was taken on a low temperature considering the amount of binder in the loose sand is considerably less than the printed sand. The sample was heated at 200 °C and was observed that there was no effect of the temperature on the binder. This can be seen in Figures 9, 10.

***Figure 8. Unprinted sand heated at 800 °C.***

***Figure 9. Unprinted sand heated at 200 °C.***

Final test was taken at 500 °C as printed sand showed results at this temperature. Similarly, like printed sand the color of this sample heated at 500 °C matched the fresh sand which can be observed in Figures 11, 12.

## GFN Analysis

Grain fineness number decreases when the binder is coated on the sand particles. GFN of the fresh sand is 66. All the samples of printed sand and loose sand were tested for their

***Figure 10. Loose sand (Unprinted).***


***Figure 11. Unprinted sand heated at 500 °C.***

GFN, and it was found that the GFN gradually increases as the temperature rises. After a certain rise it shows a constant line in the graph, which say the GFN of the reclaimed sand is achieved after 400 °C. Three tests were conducted at each temperature setting, and average of these three readings is considered for plotting the point. Figure 13 shows the comparison of GFN with temperature of printed sand which is discussed above.

Similarly, loose sand also shows same trend as the GNF increases with the temperature. Figure 14 shows the comparison of GFN with temperature of loose sand (Unprinted).

Observing both the results of GFN testing it can be stated that the GFN of 500 °C of loose sand sample as well as the printed sand sample matches the fresh sand. Printed sand showed 65.85, and loose sand showed 65.83 GFN.

## Weight Loss in Heating Analysis

A certain amount of weight loss occurs when the sand is heated in the furnace. This weight loss is also called as loss of ignition. It was observed for printed sand that the weight lost gradually increases with the temperature and remains nearly constant from 450 to 600 °C. At the end, it again shows a slight rise at 800 °C as the temperature given is excess in amount and the moisture content of sand goes on decreasing further. Figure 15 shows the weight loss in ignition of printed sand. Three tests were conducted at each

***Figure 12. Fresh sand.***

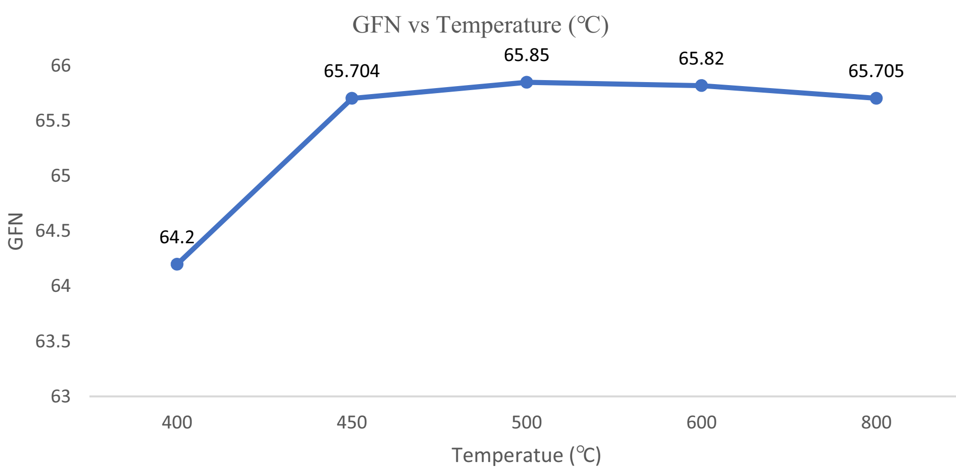


***Figure 13. GFN versus temperature (Printed sand).***

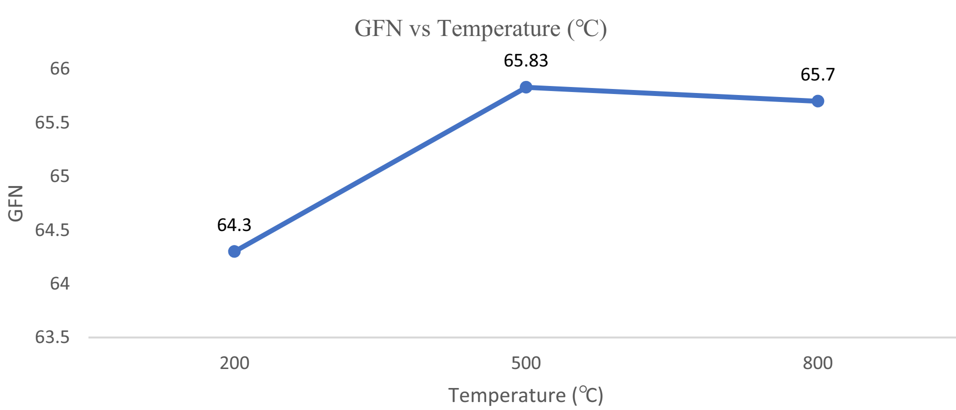


***Figure 14. GFN versus temperature (loose sand).***

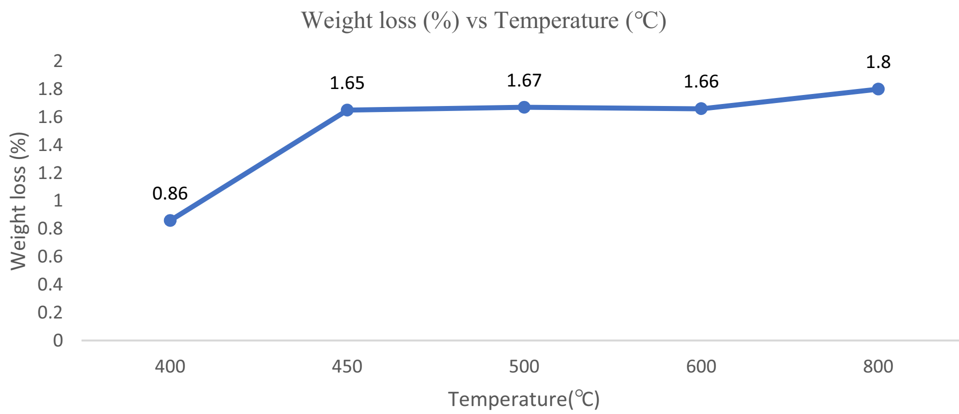


***Figure 15. Weight loss (%) versus temperature (Printed sand).***

temperature setting, and average of these three readings is considered for plotting the point.

Where as in loose sand weight loss increases as the temperature increases. Initially, for 200 °C, the weight loss is very less as there was no impact of the temperature on the binder coating of the sand. But at 500 °C it shows a rise and which continues to rise again at 800 °C. Figure 16 shows the detail study of weight loss in ignition of loose sand (Unprinted).

## PSD Analysis

It was observed that the fresh sand had the particle size of 242.59 µm. After the printing process, the particle size of the sand particles was increased due to the binder coating. Printed sand had the particle size of 256.43 µm, and loose sand had 246.22 µm. From this observation, it can be stated that the binder coating is approximately 13.84 µm for the printed sand. In the case of loose sand, the binder is in lesser amount and can vary as this sand is not printed. Figure 17 shows the detail study of PSD analysis for printed sand. Each value is obtained by average of 3 tests on each temperature.

At lower temperatures like 400 °C and 450 °C, there is not much change in particle size as the binder is not evaporated. But at 500 °C particle size matches the fresh sand particle size. Further, as the temperature rises, the particle size decreases and goes below the fresh sand particle size. This happens because at high temperature particle starts cracking and thus breaks. This again proves that these higher temperatures are overheating the sand particles and are not eligible for reclamation. Figure 18 shows the detail study of PSD analysis for loose sand (Unprinted).

Loose sand has uneven coating of binder, and thus, its particle size may vary a lot from one location to another location on the printing bed. Particle size of sample at 200 °C is not changed as there was no effect of temperature on the binder. In the case of loose sand at 500 °C, the particle size goes below fresh sand. The reason behind it is that the particle already has less and uneven coating of binder, so when the sample is given temperature, it starts cracking even at 500 °C and same occurs at 800 °C.

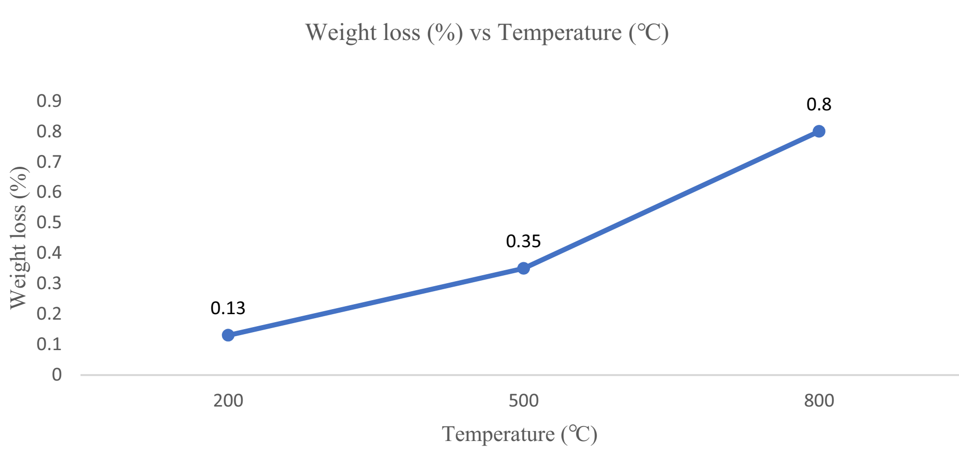


***Figure 16. Weight loss (%) versus temperature (Loose sand).***

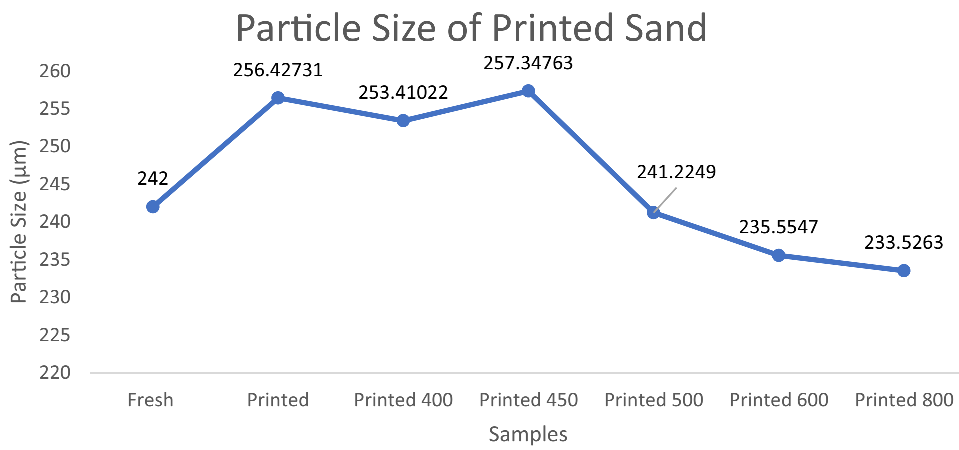


***Figure 17. Particle size versus samples of printed sand.***

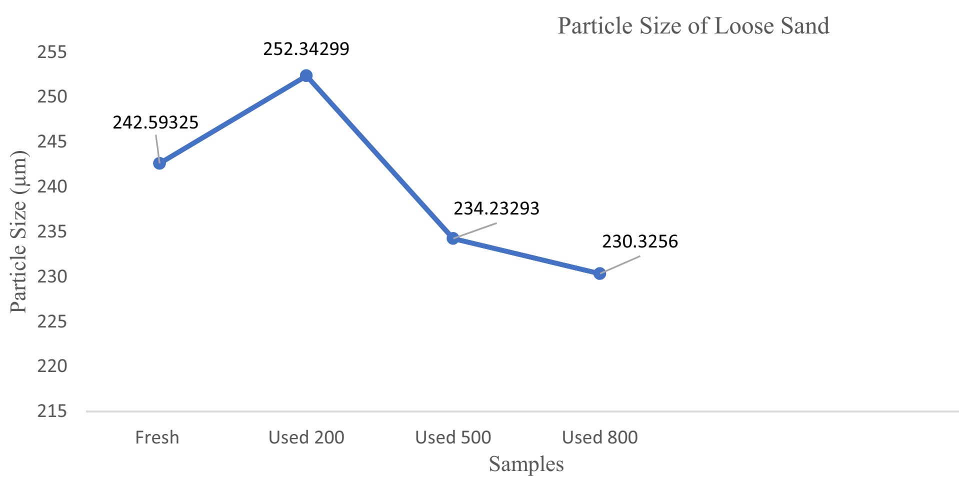


***Figure 18. Particle size versus samples of loose sand.***

## SEM Analysis

SEM (scanning electron microscope) is the key analysis of the paper which proves and supports all the analyses done for investigation of the reclaimed sand. Major findings from SEM analysis are:

1. Shape study of sand particles
2. Surface study of the sand particles
3. Binder residue on the particles
4. Effect of heat on particles at different temperatures

### *Printed Sand*

Fresh sand (GS19) is observed to be sub-angular in nature which can be seen in Figure 19. It can be observed in Figure 20 that the binder is coated on fresh sand. From the above images, the difference between fresh and printed sand can be stated.

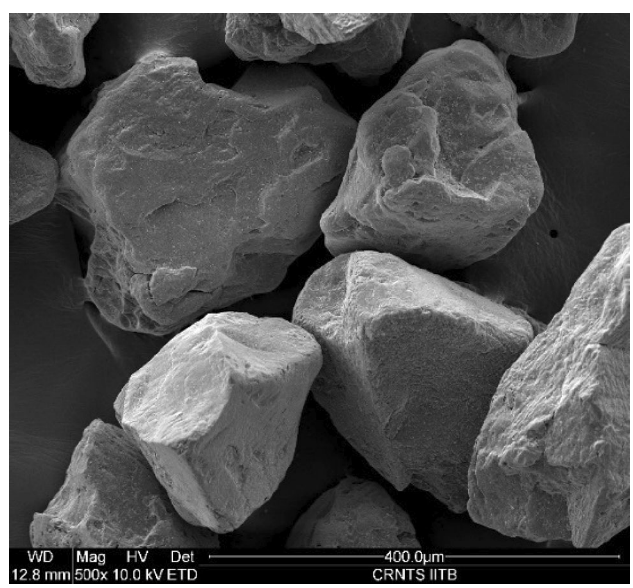


***Figure 19. Fresh sand.***

Sample heated at 400 °C can be clearly observed in Figure 21 that the binder is present over the sand particles and

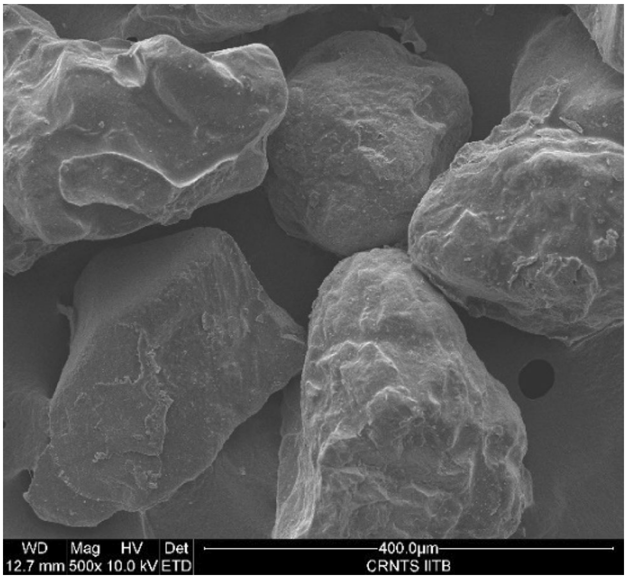


*Figure 20. Printed sand.*

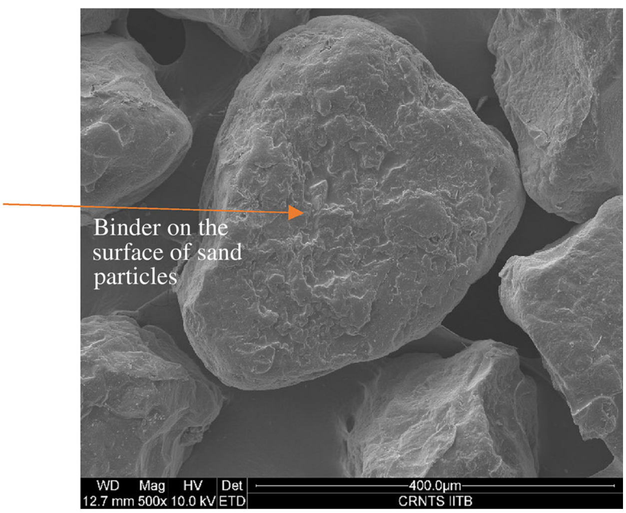


*Figure 21. Printed sand heated at 400 °C.*

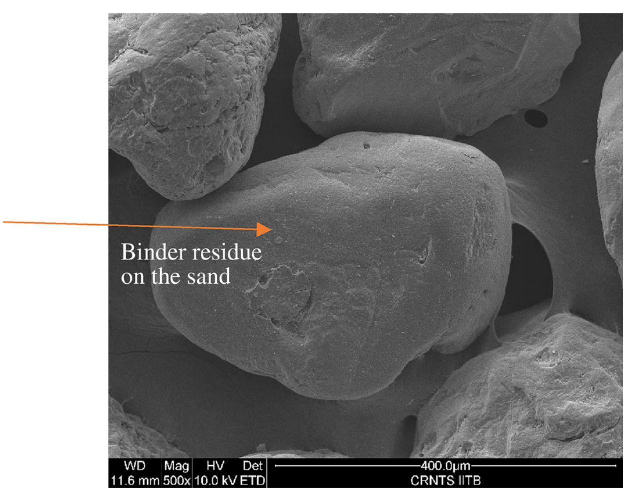


*Figure 22. Printed sand heated at 450 °C.*

proves the above results given by visual analysis, GFN and PSD analysis. This also proves that the printed sand cannot be reclaimed below 400 °C.

Sample heated at 450 °C shown in Figure 22 is observed to have a little amount of residue on the surface of sand particles. This proves that the temperature required to reclaim this GS19 3D printed sand is above 450 °C.

After observing the sample heated at 500 °C in Figure 23, it can be concluded that the binder coating over the sand particle is completely evaporated and sand is reclaimed at this temperature. Observation also states that particle does not change shape or crack at this temperature. This also supports all the results of the test and confirms that printed sand can be reclaimed at this temperature. The comparison of fresh sand and reclaimed sand can be observed in the comparison of Figures 23, 24.

The samples heated at 600 °C and 800 °C portray cracks in few particles which can be observed in Figures 25, 26. This conveys the reason behind the decrement in the particle size of these samples. Even if the binder is evaporated in these samples the extra heat energy used is colossal.

### *Loose Sand (Unprinted)*

Sample heated at 200 °C demonstrates that the binder dose on evaporate at this temperature. This can be observed in Figure 27. Binder coating can be clearly observed on the particles and this proves that the temperature for reclaiming the loose sand should be above 200 °C.

At 500 °C the sample shown in Figure 28 gets reclaimed, but also shows some cracks in the particles. Thus, this

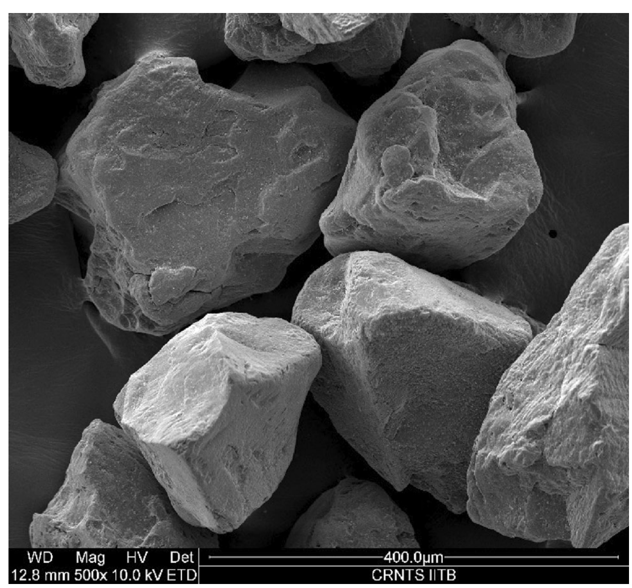


*Figure 23. Fresh sand.*

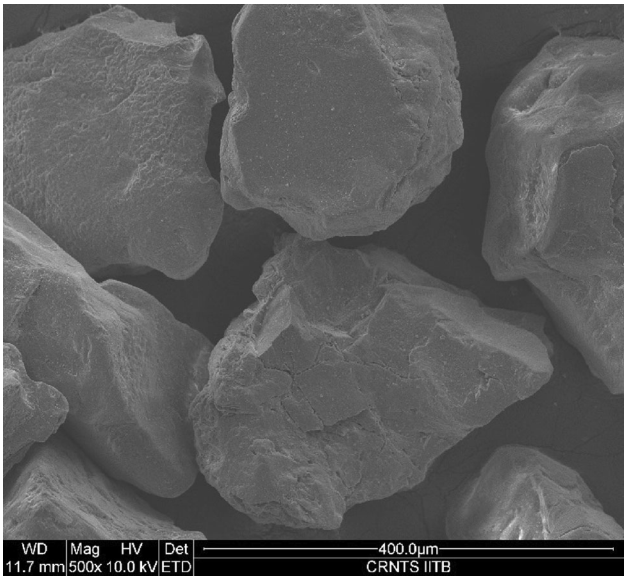


*Figure 24. Printed sand heated at 500 °C.*

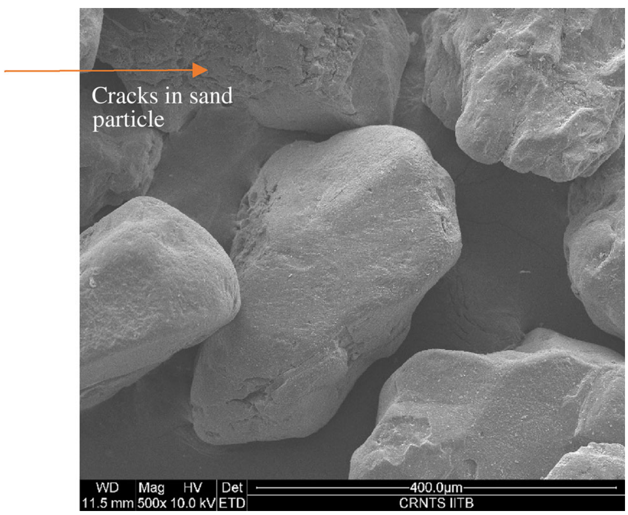


*Figure 25. Printed sand heated at 800 °C.*

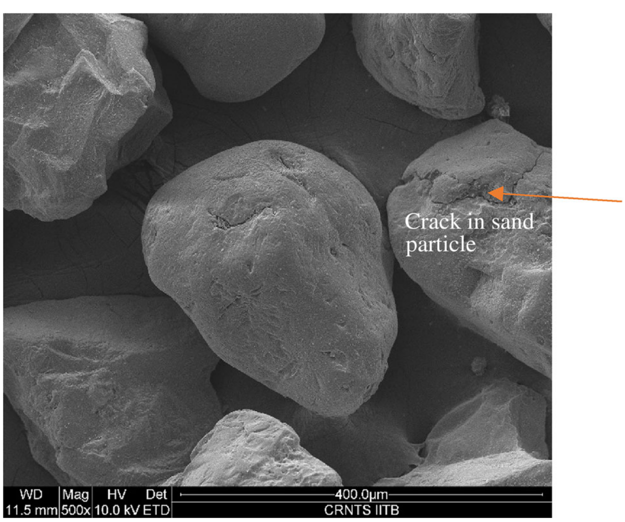


*Figure 26. Printed sand heated at 600 °C.*

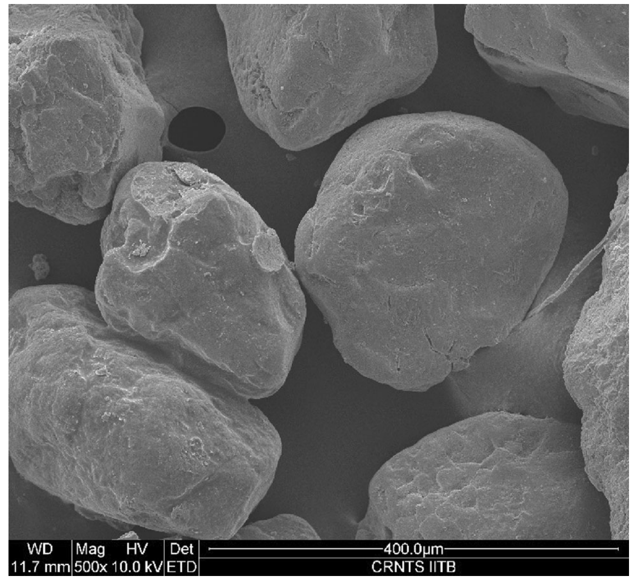


*Figure 27. Unprinted sand heated at 200 °C.*

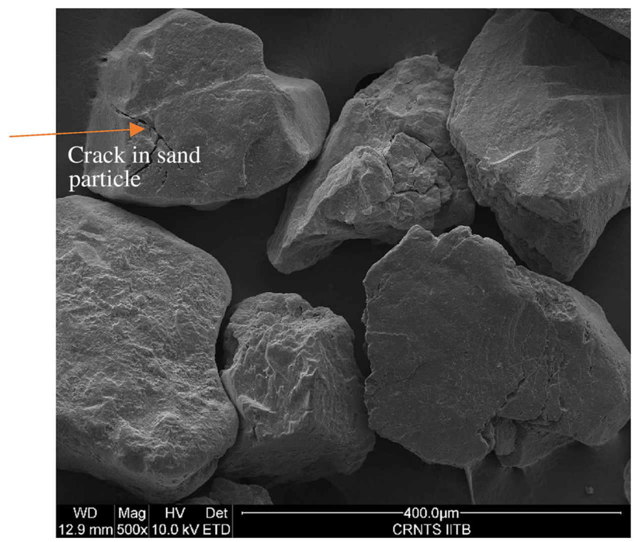


*Figure 28. Unprinted sand heated at 500 °C.*

justifies that loose sand should be reclaimed below 500 °C. Temperature for the reclamation may vary due to the variation in the amount of binder in the loose sand, but it can be reclaimed above 200 °C and below 500 °C.

This also comprises the reduction of particle size as the sample undergoes excess amount of heat.

## Conclusion

1. Suggested temperature range of temperature for reclamation of GS19 printed sand is 450–500 °C.
2. The temperature range of reclamation for loose sand can vary according to the binder content in the sand. From the above study, we can say that

loose (unprinted) sand can be reclaimed between a wide temperature range of 200–400 °C.

3. Approximately 80% of waste sand is reclaimed at 500 °C.


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