

# Assessment of South African Chromite Sand for Binder Jetting Application

Julieth Langutani Chauke<sup>1\*</sup>, Kasongo Dieder Nyembwe<sup>2</sup>, and T Mojisola<sup>2</sup>

<sup>1</sup>University of Johannesburg, Department of Metallurgy, Johannesburg, South Africa

<sup>2</sup>University of Johannesburg, Department of Metallurgy, Johannesburg, South Africa

<sup>3</sup>Air Force Institute of Technology, Department of Metallurgical and Materials, Kaduna, Nigeria

**Abstract.** Binder Jetting is an Additive manufacturing (AM) technique in which binding liquid is jetted on layers of powdered materials, selectively according to the Computer Aided Design (CAD) model to form a 3D part. One of the applications of binder jetting technology is the manufacturing of sand moulds for sand casting known as Rapid Sand Casting. Silica sand is often used in both Rapid Sand Casting and traditional moulding due to its good refractory properties coupled with its low cost. However, the use of silica sand is associated with some technical limitations, including its high thermal linear expansion and low conductivity, hence it is not appropriate to all casting applications. Chromite sand is used as an alternative refractory material to address the shortcomings of silica sand. This study assessed the suitability of South African Chromite sand for rapid sand casting. Tensile bending and compression test specimens were manufactured from different South African chromite sand samples using a Voxeljet VX 3D printer. The mechanical properties of the specimen produced using binder jetting were compared to those produced by traditional moulding. It was observed that all five printed specimens met the minimum tensile strength of 220 N/cm<sup>2</sup> for casting. Hence locally sourced South African Chromite sand can be utilised for rapid sand casting, reducing environmental impact and operational cost.

## 1 Introduction

Additive manufacturing (AM), otherwise known as 3D printing, has recently demonstrated that by using binder jetting technology, it is capable of transforming casting to the extent that it can produce sand moulds with complex geometry with reduced lead times [1]. AM is a process of fabricating physical objects from 3D model data usually by adding and binding granulated material layer by layer. Binder jetting is a 3D printing technique in which liquid is jetted selectively onto layers of powdered materials, according to the Computer Aided Design (CAD) model, to form a 3D part. 3D printing is a versatile technology that it extends into almost every sector from education, agriculture manufacturing including metal casting production [2]. One of the areas in which binder jetting technology can be used is in metal

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\* Chauke JL: [julietchauke51@gmail.com](mailto:julietchauke51@gmail.com)

casting, where it is known as rapid sand casting. Emerging research has recently shown that 3D printing using binder jetting technology is set to transform sand casting [3].

Rapid sand casting is the direct fabrication of sand moulds and cores without utilizing patterns. Pattern making is one of the slowest and most costly casting processes because it requires extremely high precision [4]. As an alternative, rapid sand casting can be utilized for its fast turnaround time and cost savings. In addition, rapid sand casting enables fabrication of complex cavities with good dimensional accuracies and freedom in the design of gating systems and metal delivery [5].

In South Africa, silica sand has been the most used refractory material in most foundry applications because of its physical properties such as its good refractoriness, reliable availability and cost effectiveness. However, the use of silica sand has some technical limitations, such as high linear expansion, low refractoriness and low thermal conductivity [5]. These limitations have made silica sand unsuitable for many types of casting. Chromite sand with its superior properties, such as good thermal conductivity, and high dimensional and thermal stability, has now been seen as an alternative to silica sand.

In recent times, most chromite sand used in the international foundry industry originates from South Africa [5]. Chromite sand has good metal chilling properties, high thermal resistance, resistance to liquid metal penetration and uniform thermal expansion thus minimizing finning problems [6]. Chromite sand is usable with all types of steels and is particularly suitable for parts made of chrome, chrome nickel and manganese steel [7]. Although chromite sand has superior properties, silica sand is still in use for many castings in South Africa. This might not be unconnected with the high cost of chromite sand compared to silica sand.

As the recommended moulding sands for 3D printing are very expensive, to overcome this challenge and find a cheaper and lasting solution, in 2019 Hodder and Chalaturnyk asked the following question: “Can traditional foundry or non-standard sand be used in 3D printing?” The answer to the question might be essentially “yes”, however it has to be established that the sand can flow easily, otherwise it might lead to casts with below-standard mechanical properties resulting in poor dimensional accuracy due to the absence of compaction as the sand is deposited [7].

In 2016, Nyembwe and his co-workers evaluated the suitability of high quality South African silica sand for use in the Voxeljet VX1000 3D printer to make foundry-quality mould and cores while comparing its properties to those of the more expensive imported silica sand recommended by Voxeljet. It was found that South African silica sand produced better sand moulds and cores in the Voxeljet VX1000 3D printer than the imported silica sand [8].

In another study, Nyembwe et al. 2016 studied the physical properties of sand casting parts produced using a VoxelJet VX1000 3D printer. It was observed that post-processing or curing sand moulds significantly improved the tensile and bend strength as well as the friability of the mould. However, they also found that castings produced from 3D-printed sand moulds had poorer dimensional accuracy, inferior and rougher surface finish than conventional castings [8]. Most studies performed on the suitability of non-standard or traditional foundry sand on binder jetting are based on silica sand as it is the most commonly used refractory material in metal casting.

There is limited literature on the use of chromite sand, especially South African chromite sand, for both binder jetting and conventional casting processes. This study, therefore,

examines the suitability of South African chromite sand for binder jetting applications. In addition, the study also pays particular attention to the superior properties of castings from chromite sands.

## 2 Methodology

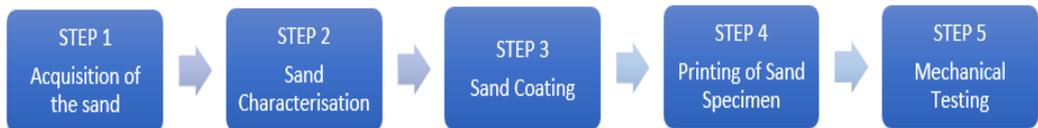
This section covers the properties of the raw materials used in the study and the experimental procedure in terms of the tests performed in the course of the study.

### Raw Materials:

- Five commercially available South African chromite sand samples (labelled A, B, C, D and E) of the same grade were obtained from five major South African suppliers.
- The furan no-bake (FNB) process was used for the rapid sand casting. Furfuryl alcohol was used as the binder/resin.
- Aryl-sulphonic acid was used as the catalyst/activator.

### 2.1 Experimental Procedure

The experimental procedure adopted in this study was divided into 5 steps (see Fig. 1). Steps 1 and 2 have been reported in our previous paper titled: Evaluation of local chromite sands for rapid sand casting applications [8]. This paper focuses on steps 3, 4 and 5.



**Fig. 1.** Experimental work stages adopted in the study.

#### 2.1.1 Sand Coating

Flowability of sand is one of the most significant sand parameters in binder jetting technology. Voxeljet 3D printer requires the sand to be precoated with a catalyst to allow for acid evaporation to improve the flowability of the sand. To ensure this, two days prior to printing of the sand samples, the sands were coated with 0.3% arylsulphonic acid and thereafter spread on the floor to allow for acid evaporation, shown in Fig. 2. This coating stage was included to ensure that sand did not clog the recoater due to poor flowability.



**Fig. 2.** Coated sand prior to printing.

### 2.1.2 Printing of Sand Specimens

The 3D printing process started by loading the coated sand in the sand hopper, followed by setting up the printing parameters as well as ensuring the sand had good flowability by allowing the recoater to deposit layers of sand and to set up a good base for the print job. A Voxeljet 3D printer is shown in Fig. 3 (a). Fig. 3 (b) shows a CAD layout of the sand specimen. The print head and recoater are shown in Figs. 3 (c) and (d), respectively. On average, a single print job takes approximately 3 hours to complete. All five samples were printed with 4% resin addition. The resin and catalyst proportions as used in this study were based on our previous work done on optimization of chromite sand additives for rapid sand casting applications [9].



**Fig. 3.** (a) Voxeljet 3D printer (b) CAD design of the parts (c) Print head in progress (d) Recoater in progress.

After printing, the samples were left overnight on the print box and taken out the following morning. All excess sand was gently brushed off and the samples put through the final stage of post processing. The printed sand specimens are shown in Fig 4.



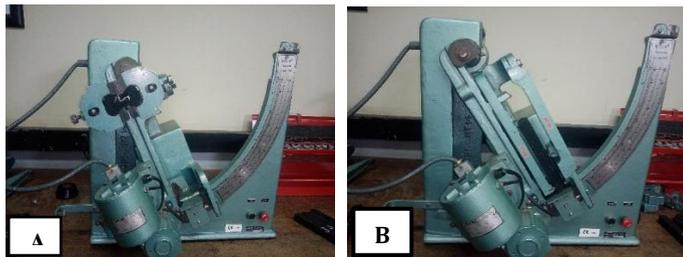
**Fig 4:** Image showing the 3D printed sand specimen (Tensile, Transverse and Compression)

### 2.1.3 Mechanical testing

The mechanical tests performed were tensile testing, bend or transverse testing, compression testing and friability testing. Three specimens were manufactured and tested for each test category and the average was used. Fig 4 shows a set of the sand specimens manufactured on the Voxeljet VX 3D printer. Mechanical testing was done on the cured and uncured states. Sample Curing involves heat treatment in a ventilated oven at 110 degree Celsius for two hours. The curing step is aimed at fully developing the strength of the printed sand sample.

#### Tensile, bend and compression testing

Tensile, bend and compression strengths were tested in a Ridsale foundry universal strength tester to determine the strength of the printed sand specimen. Figure 5 (a) shows the tensile testing whereas 5 (b) shows transverse testing setup. The minimum required strength is for printed sand parts 220 N/cm<sup>2</sup>. However this minimum strength required is based on silica sand. The bulk density of chromite sand (2.6 g/cm<sup>3</sup>) is nearly twice the bulk density of silica sand (1.54 g/cm<sup>3</sup>), therefore the strength of chromite sand should be higher.



**Fig 5:** Universal strength tester showing the different tests performed

#### Friability testing

Friability measures the ability of the bonded sand to resist surface abrasion. Friability measurements were taken following the AFS 248-00-S standard procedure. Two standard 50 x 50mm cylindrical specimens were placed side by side in the rotary screen of the friability meter, touching each other and with their ends in contact with the supporting plate. The machine was then run for 30 seconds while the abraded sand was collected and weighed. Friability measures the ability of the mould or core to resist abrasion during pouring and throughout the solidification process. The friability percentage is calculated using the

equation below. A good friability value must not exceed 11% otherwise the sand would have a tendency towards dirt defects and a loss of casting surface quality.

$$\% \text{ Friability} = \left( \frac{A}{B+C} \right) \times 100 \tag{1}$$

Where:

A = weight collected in a pan

B = weight of the first specimen

C = weight of the second specimen

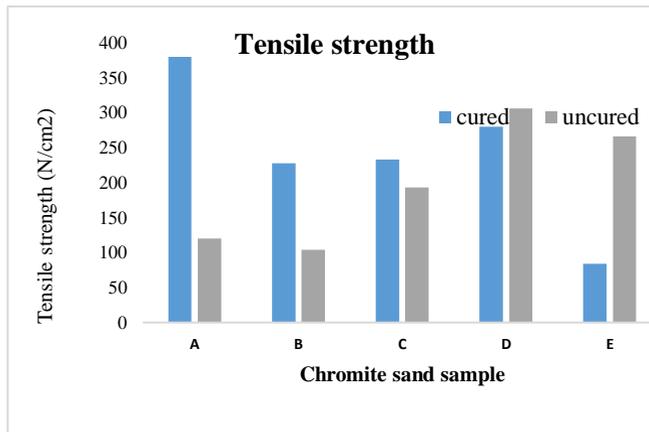


**Fig 6:** Friability testing equipment

## 3 Results and Discussions

### 3.1 Tensile Strength

The Tensile strength results in Fig. 7 shows the tensile strength results of the five samples. The highest tensile strength was achieved in sample A with 380 N/cm<sup>2</sup> in cured state and the lowest is sample E with 84 N/cm<sup>2</sup> also cured. Generally the uncured samples are lower except in case of sample D and E. It is possible that the higher ADV of the samples could be the reason for this apparent anomaly [8]



**Fig 7:** Tensile strength results.

Sample A had the highest cured strength of 380 N/cm<sup>2</sup>, but there was a huge strength difference in the cured and uncured states of the sample. In a previous study [9], it was found that samples with high pH such as sample B, generally have lower tensile strength in their uncured state. Since furfuryl alcohol is an acid-catalysed bonding system, the high amount of basic materials in the sand reduces the bonding ability of the sand mixture. Hence, sample B was found to have a low tensile strength of 228 N/cm<sup>2</sup> even though it had the lowest Acid Demand Value (ADV). However, the heat curing process was found to increase the strength as the heat-cured samples have higher strength than the uncured samples.

### 3.2 Bend Strength

The bend strength results, as shown in Fig. 8, show that sample D had the highest bend strength of 638 N/cm<sup>2</sup> followed by sample A with 570 N/cm<sup>2</sup>. In addition, all the samples met the mould bend strength requirement, which is above 220 N/cm<sup>2</sup> as per Voxeljet specifications. There was a minor difference in the strength results for the cured and uncured samples. This difference was because of the heat curing process, which was found to increase the sand strength as detailed above.

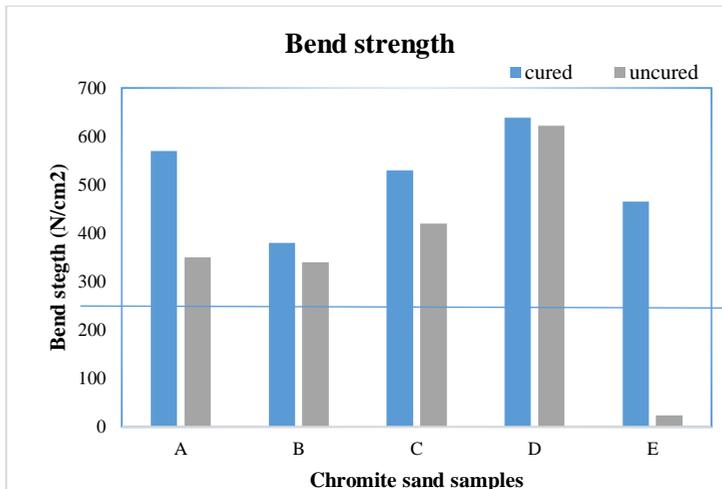
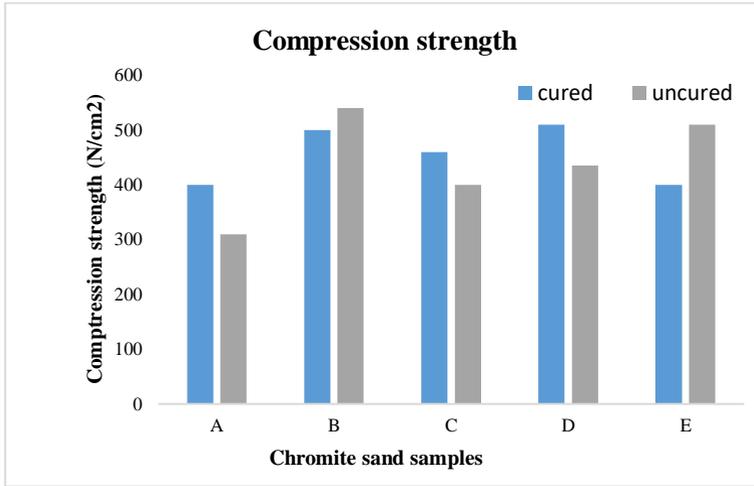


Fig. 8. Bend strength results.

### 3.3 Compression Strength

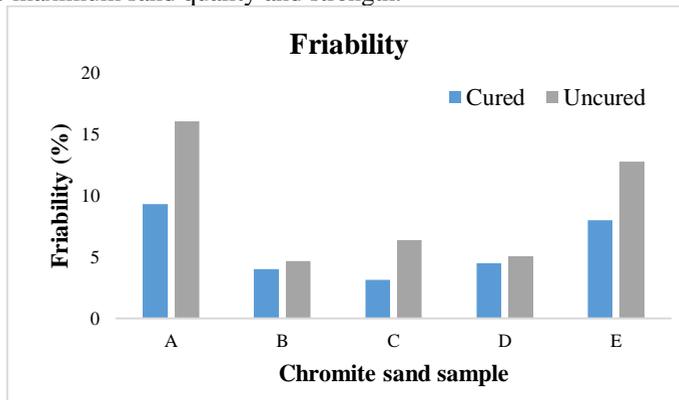
The compression strength, as presented in Fig. 9, shows that there were minor differences in the strengths of the five samples compared to other tests. This is because most of the sand samples did not fail during testing and the maximum strength value on the universal strength tester was recorded.



**Fig. 9.** Compression strength results.

### 3.4 Friability

The heat curing process was applied to the printed samples to reduce their friability in order to achieve the maximum sand quality and strength.



**Fig. 10.** Friability results

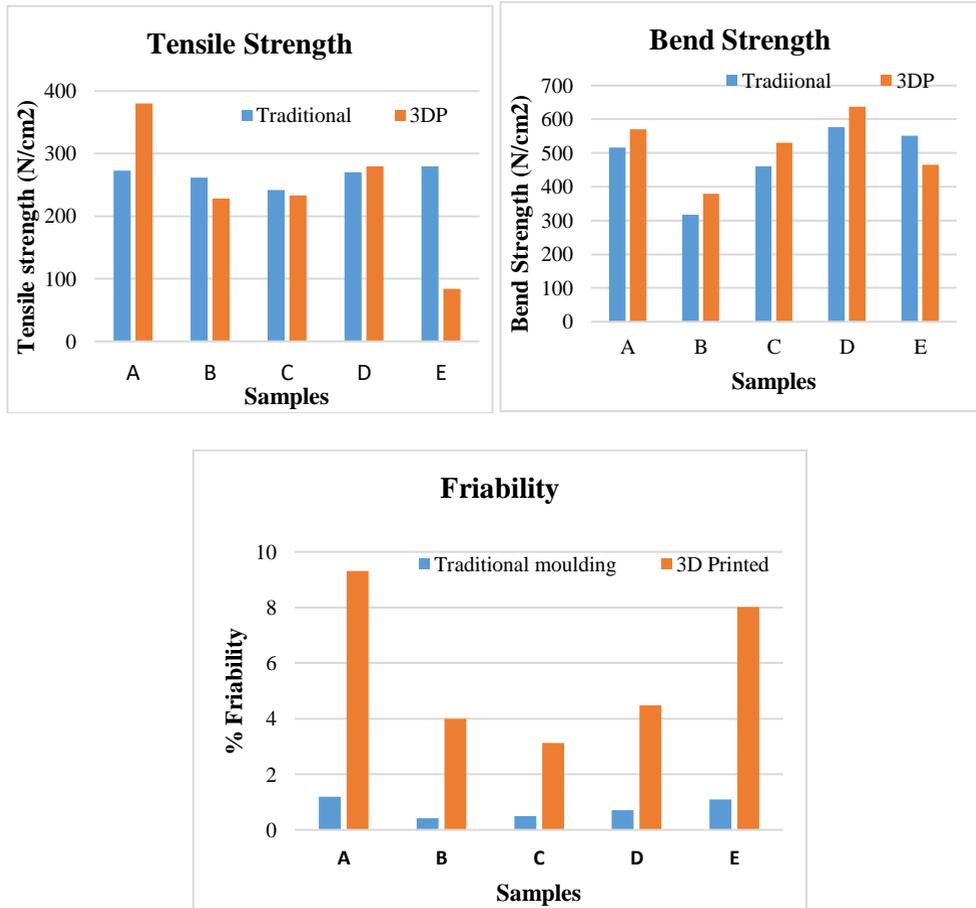
It was observed that the uncured 3D printed samples A and E had a high friability, above the maximum requirement of 11%, with 16.04% and 12.76% friability respectively. After curing, the friability of all the samples improved, with even samples A and E falling below the maximum friability requirement.

### 3.5 Comparison of Traditional Moulding Sand and Rapid Sand Casting

The results of sand samples produced via traditional moulding method in a previous study [9] were compared with those produced by 3D printing in figure 11.

Fig. 11 shows that the 3D printed samples had superior properties compared to the samples produced via the traditional foundry moulding process, especially in tensile strength. This is because in rapid sand casting 4% furfuryl alcohol was added to each deposited layer until

build box completion. Whist with the traditional moulding process, 4% furfuryl alcohol was added during sand mixing. On the other hand, the friability results revealed that the 3D printed samples were more friable than the traditional manufactured sand samples. This is because during traditional moulding, the sand is rammed into the pattern thereby increasing the sand compaction and interlocking of the sand grains. However, in 3D printing the recoater vibrates to spread the sand grains with no compaction taking place. Hence the 3D printed sand samples are more friable, i.e. easily crumbled as required during the shakeout.



**Fig. 11.** Strength results for cured samples made using traditional moulding and 3D printing.

The high friability measured for samples A and E appears to align with a previous study on the characterisation of the same chromite sand samples [10]. The latter investigation showed that samples A and E were outliers, having high acid demand values.

## 4 Conclusion

In this study, the suitability and performance of South African chromite sands for binder jetting was assessed. The investigation showed that adequate moulding properties could be achieved with three dimensional printed parts on a Voxeljet VX 1000 using local Chromite sand. In particular, the required minimum bend strength of 220 N/cm<sup>2</sup> for sand casting was met by all five Chromite sand samples. As such, this study has established that South African chromite sand can be used for binder jetting sand casting applications. Chromite sand has numerous advantages compared to silica sand for special casting applications, including its higher refractoriness, low linear thermal expansion and chilling effect suitable for special casting applications. The study also provides an additional beneficiation application of local Chromite sand in the Fourth Industrial Revolution (4IR) world. Future work will involve casting real metallic components from chromite sand moulds and cores printed by Additive Manufacturing (AM) processes.

## 5 References

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