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# Evaluation of Foundry Properties of Brahmaputra River Sand and its Prospects

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## Abstract

The river system of the Bengal delta encompasses a huge amount of fluvial sand; however, no comprehensive studies were available on using this river sand in foundry industries. Hence, the present research evaluates the foundry properties of trans-boundary Brahmaputra River sand and its prospects for use in foundries. Several laboratory analyses have been performed to elicit the foundry properties using standard methods of foundry analysis, including XRD, XRF, TG-DSC, and FESEM. From the study, the sand contains mainly quartz with small amounts of feldspar, amphibole, chlorite, and mica, and exhibits a subangular to subrounded shape. The sand is dominated by $SiO_2$ (67.81–69.97%) and lesser amounts of other oxides, and it is thermally stable within 1000 °C temperature. The grain fineness number (64–79), mineralogical, chemical, thermal, and foundry properties are suitable for non-ferrous metal casting without distortion. Further, the aluminum and zinc alloy casting with trials demonstrate their potential for use in the foundry industries. The outcomes of this study thus offer valuable information about utilizing Brahmaputra River sand for foundry applications.

**Keywords:** Foundry properties, Grain fineness number, Green strength, Metal casting, River sand

## 1. Introduction

Sands are being used as the major moulding materials worldwide in the foundry industries owing to its refractory nature, chemical resistivity, availability, relatively low cost, high efficiency, and reuse cycles [1-2]. The foundry industry uses various types of sand, e.g., silica, olivine, chromite, zirconia, staurolite [3]. The non-plastic silica sand with a binding agent to bind the sand particles together and can facilitate a mould mixture to hold its shape. Generally, foundry green sand is composed of high-quality refractory silica sand (85–95%), cohesive bentonite clay (4–10%) as a binder, an optional carbonaceous material (2–10%) as an additive to enhance the casting surface smoothness, and 2–5% water [4]. The foundry properties of green sand vary with the physical (size, shape, and density) and chemical (composition, fusion temperature, and reactivity nature) characteristics of moulding sand particles [5]. The quality and smoothness of a casting depends on the physical and chemical properties of the major moulding materials used [5]. Though the metal casting by using sand mould is the oldest technology, the suitability of local sand using in foundry is an open field of research in many parts of the world. Nayak and Sadarang [6] studied the suitability of Mahanadi riverbed sand (MRS), India and Hussain et al. [7] studied the Perak River sand, Malaysia for foundry applications. They found that the river sand is used as an alternative to silica sand for non-ferrous metal casting.

To date, no comprehensive studies have been available on the foundry sands of Bangladesh, though the country has numerous potential sources of sand. For example, the Ganges-Brahmaputra-Meghna (GBM) river systems carry the world's largest sediment load estimated about 1.0 to 2.4 billion tonnes/year [8]. Thus, the availability of river sand in Bangladesh encourages the present investigation to unfold their properties for foundry use. In addition, countless in-channel sand bars are formed in the GBM river systems, and the sand from these bars could be used in the foundry industries. However, most of the foundries in Bangladesh have been using procured sand from outside of the country for non-ferrous and ferrous metal casting, which increases the casting cost.

Therefore, the aim of this research is to unravel the foundry characteristics of trans-boundary Brahmaputra River sand and infer its prospects for foundry applications.

## 2. Location, materials and methods

The raw materials (e.g., river sand) used in this research were collected from nine separate locations of the Brahmaputra River, Chilmari, Kurigram, Bangladesh (Fig. 1). An additional two (02) reference/benchmark samples were also used for performing foundry test for the purpose of comparison. The ASTM graded sand (ASTM C778 [9]) sample, origin-France, is designated by Ref 1, and the commercial silica foundry sand sample is designated as Ref 2.

The study area lies in between 25°31'30"N to 25°33'37"N latitude and 89°40'30"E to 89°41'42"E longitude (Fig. 1). To characterize the foundry sand, a series of laboratory analyses have been performed, *viz.*, morphology delineation, microscopic study, chemical analysis, thermal analysis, and green sand properties. Optical stereo-microscopic analysis was performed to delineate the mineralogy and grain shape of sand samples to be mould. The crystalline phase identification of the sand samples was completed by X-ray diffraction (XRD) analysis using a *Panalytical XPERT-PRO (PW3040/60)* with a continuous scanning speed of 2 °2θ/min. The chemical composition was obtained using a *Rigaku ZSX Primus* wavelength dispersive X-ray florescence (WDXRF) spectrometer. The thermogravimetry (TG) and differential scanning calorimetry (DSC) of a dry sand sample were measured by *STA 8000* (*PerkinElmer, USA*) with a heating rate of 20 °C/min. The specific gravity, particle size distribution, and loss-on-ignition were determined in accordance with ASTM D854 [10], ASTM D422 [11], and ASTM D7348 [12] respectively. The grain fineness number (GFN), clay content, and bulk density have been done based on IS 1918 [13]. *Jenway 3510* (UK) pH meter was used for the determination of pH and Acid Demand Value (ADV) of a sand specimen according to AFS [14]. The field-emission scanning electron microscope (FESEM) imaging was performed by using *ZEISS Sigma 300* (Carl Zeiss Ltd., UK).

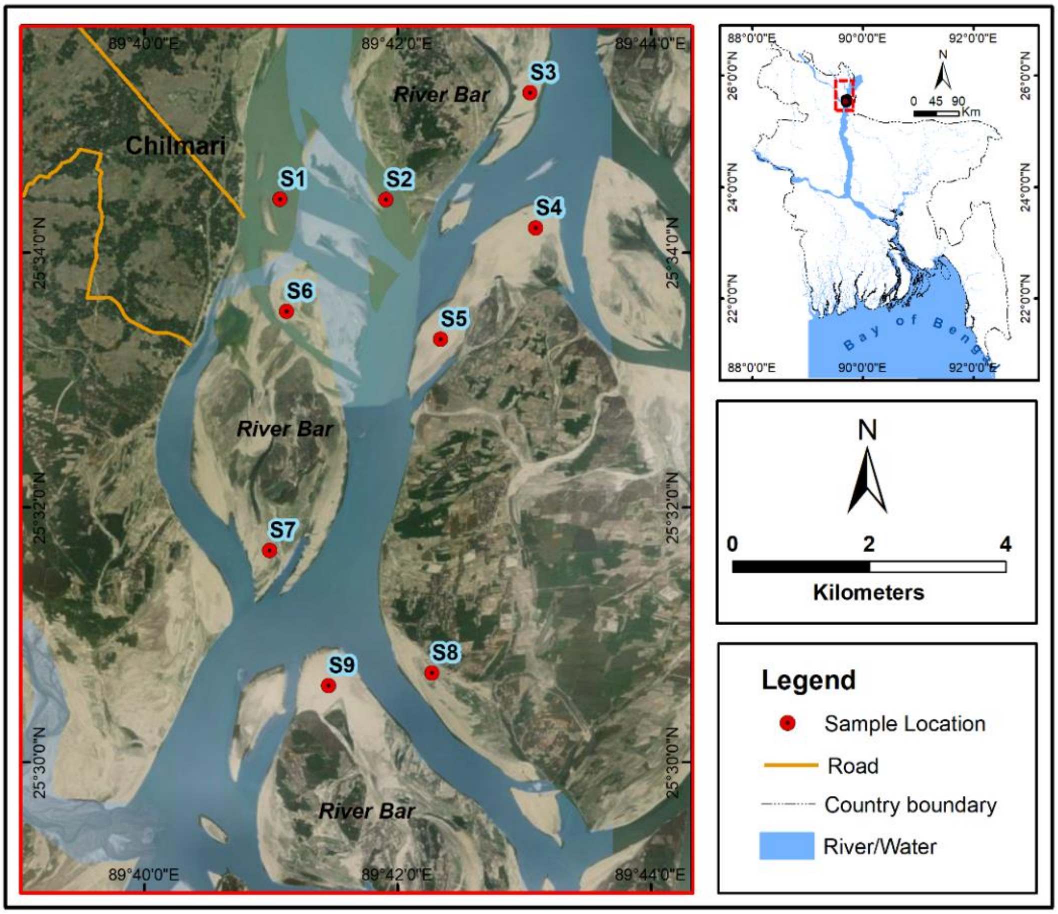


Fig. 1. Sampling location map in the Brahmaputra River, Bangladesh

To determine the green sand properties, the sand mixture was prepared by mixing the dry river sand (83%), bentonite clay (10%) as binder, graphite (2%) as additive, and water (5%) according to IS 1918 [13]. This optimum mould composition was determined by the systematic laboratory trial and error method, which found the present composition to be most favorable. Afterward, the sand mixture was appropriately mulled for 4-5 minutes by the automatic muller, and then the mixture was transferred to a splitable specimen tube of the standard sand rammer. The standard sand mould of Ø50 mm×50 mm in height was prepared by weighing out 155±2 grams sand mixture, and for each test, three specimens of similar dimensions were prepared. After three times of ramming the sand sample, the test piece was carefully extracted from the tube. This type of test piece was used in various tests, including green compression and shear strength, compactability, air permeability, hardness, flowability, and shatter index according to IS 1918 [13]. Thus, each of the aforesaid tests was repeated three times, and the average result was recorded. The compression and shear strength, and compactability tests were executed by a hand-operated universal sand strength machine. The air permeability, hardness, flowability, and shatter index were determined by the permeability meter, mould hardness tester 'B' scale, flowability tester, and shatter index tester, respectively. The manufacturing company of this equipment is Kelsons Testing Equipments, Shiroli, Kolhapur, India. The casting porosity was measured based on the density measurements, i.e., casting porosity (%) = {(theoretical density–actual density)/theoretical density}×100 [2].

# 3. Results and discussion

## 3.1. Mineralogy

### 3.1.1. Optical analysis

The Brahmaputra River sand is physically characterized by light grey in color, medium to fine grained, and friable when dry. Optical analysis by stereo-microscope exhibits the specimens (S1, S4, S7, and S9) might be composed of quartz, feldspar, mica, and some opaque minerals (Fig. 2). The shape of the mineral grains is sub-angular to sub-rounded with low sphericity, as visualized from the optical image (Fig. 2). This type of shape and roundness implies that the sand of the study area is experienced by relatively less transportation from the provenance to the place of deposition. Besides, the Ref 1 and Ref 2 sands are entirely composed of quartz, and the shape of the Ref 1 sample is rounded to sub-rounded with high sphericity, whereas, sub-angular to sub-rounded shape with low sphericity for Ref 2 specimen.

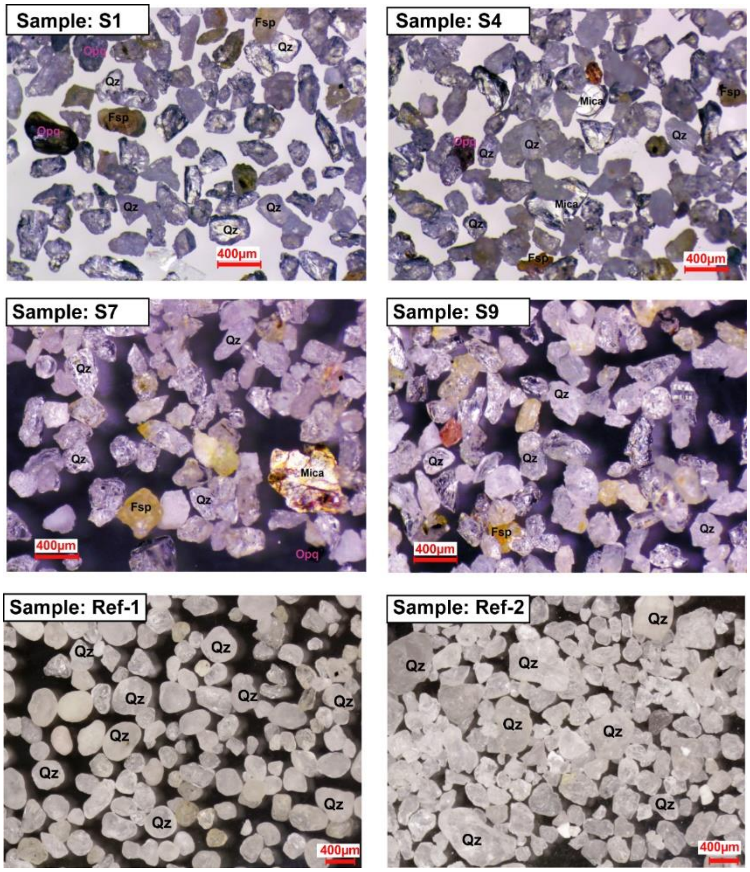

Fig. 2. Photo-micrographs of sand from the Brahmaputra River (mineral symbols after Whitney and Evans [15])

**3.1.2. XRD analysis**

The complementary XRD analysis of the Brahmaputra River sample (S1, S4, S7, and S9) along with reference specimens (Ref 1, Ref 2) was accomplished and from the XRD spectroscopy, the reference sand is entirely composed of quartz. On the other hand, the studied sand specimen is primarily composed of quartz ($SiO_2$) with a small amount of feldspar, amphibole, chlorite, and mica (Fig. 3). The intensity of quartz peak is relatively higher than other mineral peaks in the diffraction pattern, which indicates that the dominant phase is quartz. This higher quartz ($SiO_2$) would enhance the green sand mould's permeability, refractoriness, and chemical resistivity and be advantageous for its better mouldability for casting [2]. The peak intensity of impurity minerals, e.g., feldspar, amphibole, chlorite, and mica, is comparatively much lower than that of quartz, as shown in XRD patterns, implying their nominal percentage in the sands. These impurity minerals might not cause issues when casting non-ferrous metals [6]. The results of XRD analysis are consistent with the microscopic investigation of the same specimen (Fig. 2).

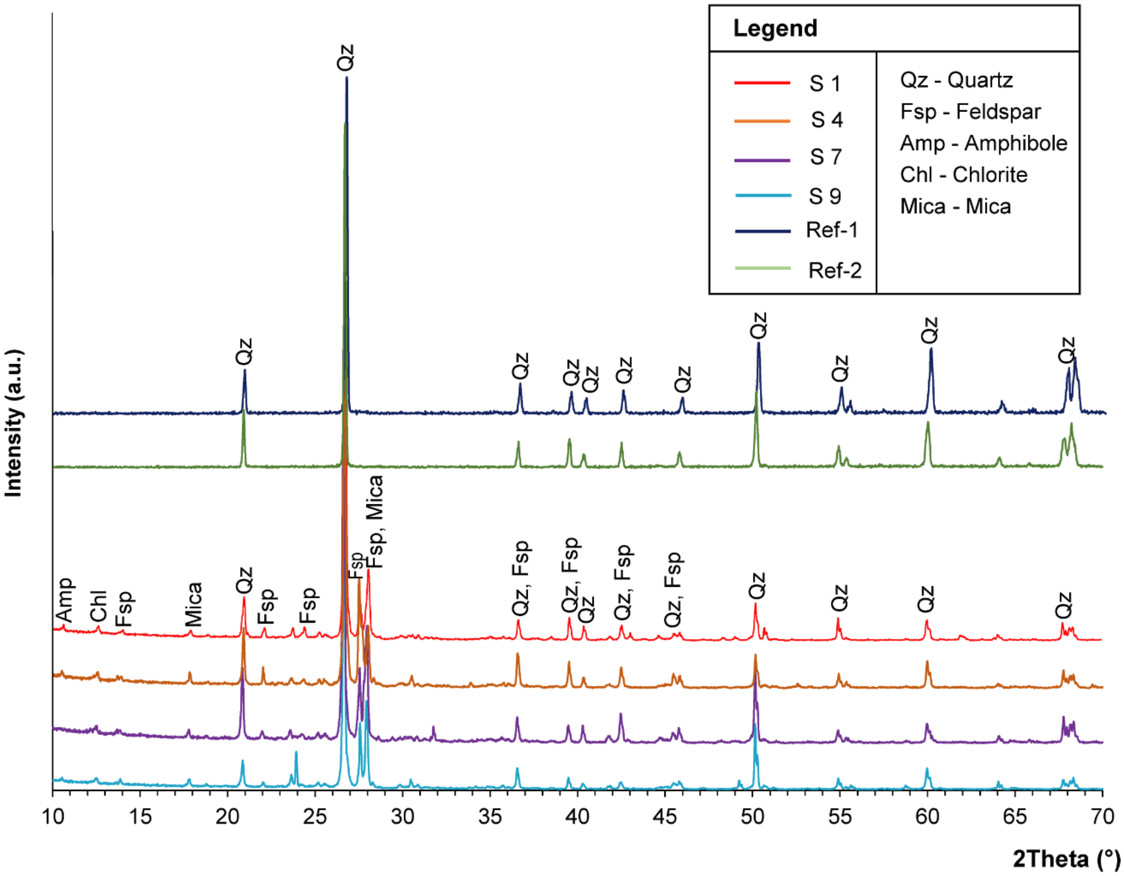


Fig. 3. XRD pattern of sand specimen from the Brahmaputra River

## 3.2. Chemical composition

The sand specimens (S1, S4, S7, and S9) are dominantly composed of $SiO_2$ (67.81–69.97%), $Al_2O_3$ (12.12–13.45%), $Fe_2O_3^t$ (6.0–6.47%), and CaO (3.36–3.74%), with minor amounts of $K_2O$, MgO, $Na_2O$, and other oxides <1.0% (Table 1). Chemically, the MRS sand [6] is nearly consistent with our studied Brahmaputra River sand (Table 1). On the other hand, the Ref 1 and Ref 2 sand are principally composed of 96.15–97.27% $SiO_2$ with 0.83–1.08% $Al_2O_3$, 0.81–1.38% iron oxides as $Fe_2O_3^t$, and other oxides <1.5% (Table 1). The chemical composition result of the analyzed sample illustrates that it has a comparatively lower $SiO_2$ (67.81–69.97%) content than the typical silica sand ($SiO_2$=95-97%) and MRS sand (79.85%), which might reduce the refractoriness [16]. Thus, the studied sand can be categorized as silica-dominated sand instead of silica sand based on the presence of oxides of silicon percentages. This low silica in the sand may not suited for high temperature metal casting (e.g., iron, steel), as at high temperatures the oxides of aluminum, calcium, and iron might react with the metal to be melt. Yet, the foundry suitability depends not only on the silica percentages but also incorporates with other foundry properties (e.g., GFN, green strength, permeability, hardness, flowability etc.). However, the existing oxides in the sand may not react with the metal to be melted at low temperatures, making it appropriate for casting non-ferrous metals.

Table 1.
Chemical composition of the Brahmaputra River sand specimen

| Major Oxides (wt%) | S1 | S4 | S7 | S9 | Average | Mahanadi Riverbed Sand [6] | Ref 1 | Ref 2 |
|---|---|---|---|---|---|---|---|---|
| $Na_2O$ | 1.84 | 1.93 | 1.78 | 1.95 | 1.88 | 0.38 | 0.08 | - |
| $MgO$ | 1.78 | 1.61 | 2.01 | 1.65 | 1.76 | 0.36 | - | - |
| $Al_2O_3$ | 12.96 | 12.25 | 13.45 | 12.12 | 12.70 | 4.81 | 1.08 | 0.83 |
| $SiO_2$ | 68.90 | 69.97 | 67.81 | 69.33 | 69.00 | 79.85 | 96.15 | 97.27 |
| $P_2O_5$ | 0.19 | 0.18 | 0.18 | 0.20 | 0.19 | 0.11 | 0.01 | 0.31 |
| $K_2O$ | 3.01 | 2.98 | 3.47 | 2.89 | 3.09 | 0.27 | 0.60 | 0.01 |
| $CaO$ | 3.62 | 3.36 | 3.74 | 3.71 | 3.61 | 0.59 | 0.04 | 0.33 |
| $TiO_2$ | 0.68 | 0.65 | 0.75 | 0.84 | 0.73 | 5.63 | 0.04 | 0.06 |
| $Cr_2O_3$ | 0.51 | 0.68 | 0.40 | 0.44 | 0.51 | - | 0.51 | 0.32 |
| $MnO$ | 0.14 | 0.12 | 0.12 | 0.12 | 0.13 | - | - | - |
| *$Fe_2O_3^t$ | 6.10 | 6.02 | 6.00 | 6.47 | 6.15 | 7.47 | 1.38 | 0.81 |
| Others | 0.27 | 0.25 | 0.29 | 0.28 | 0.27 | 0.53 | 0.11 | 0.06 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

** $Fe_2O_3^t$ = Total Iron Oxides*

## 3.3. Particle size distribution and grain fineness number

The particle size distribution (Table 2) and graph (Fig. 4) show that the sand is medium- to fine-grained with a narrow distribution, which may affect the quality of the castings. The medium to fine grain size of Brahmaputra sand is useful for better surface finishing during metal casting [17], as the coarse-grained sand allows metal penetration into the moulds [16]. The majority of sand fractions are retained in between +90 μm and -355 μm mesh for analyzed samples, whereas for reference samples (Ref 1 and Ref 2) the sand ranges from +180 μm to -1000 μm size mesh (Table 2). Rao [17] mentioned that, the majority of sand distributed over 3 or 4 successive sieves is suitable for moulding and this statement is consistent with the analyzed sand, which belongs mainly the BS sieve mesh 60, 85, 120. Although some of the sand fraction is retained over 500 μm and below 90 μm, this could be eliminated by sieving to obtain good quality casting sand [7]. Referring to Figure 4, the reference sand is mainly medium-grain sand, although the analyzed sand is medium- to fine-grain. Both types of sand give narrow distributions obtained from the grain size distribution curves (Fig. 4), which signifies that uniform size in gradation.

Table 2.
Particle size distribution, grain fineness number (GFN), and average size of sand specimen

| BS standard sieve mesh | Mesh size (mm) | Retained (gm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | Ref 1 | Ref 2 |
| #16 | 1.00 | 0.02 | 0.06 | 0.05 | 0.13 | 0.04 | 0.13 | 0.04 | 0.13 | 0.11 | 0 | 0 |
| #30 | 0.50 | 0.82 | 0.83 | 0.92 | 1.26 | 1.01 | 1.29 | 1.76 | 1.85 | 1.67 | 21.62 | 18.75 |
| #44 | 0.355 | 7.46 | 6.63 | 6.39 | 8.81 | 7.97 | 6.81 | 9.62 | 9.86 | 8.45 | 46.92 | 32.69 |
| #60 | 0.250 | 31.00 | 28.14 | 28.14 | 29.89 | 28.65 | 20.73 | 26.72 | 27.56 | 28.13 | 26.82 | 35.30 |
| #85 | 0.180 | 33.47 | 33.71 | 35.14 | 33.21 | 28.66 | 27.15 | 27.53 | 27.36 | 28.51 | 3.99 | 10.40 |
| #120 | 0.125 | 18.36 | 20.11 | 18.68 | 17.42 | 18.02 | 24.26 | 17.62 | 18.23 | 17.28 | 0.34 | 2.66 |
| #170 | 0.090 | 5.77 | 6.84 | 6.84 | 5.32 | 8.84 | 11.19 | 9.22 | 8.50 | 8.66 | 0 | 0.10 |
| #240 | 0.063 | 2.07 | 2.44 | 2.50 | 2.38 | 4.52 | 6.00 | 5.03 | 4.49 | 4.92 | 0 | 0 |
| #350 | 0.045 | 0.52 | 0.53 | 0.64 | 0.62 | 1.25 | 1.71 | 1.27 | 1.19 | 1.31 | 0 | 0 |
| Pan | - | 0.26 | 0.28 | 0.61 | 0.39 | 0.60 | 0.71 | 0.62 | 0.45 | 0.52 | 0 | 0 |
| Grain Fineness Number | | 64 | 67 | 68 | 64 | 71 | 79 | 72 | 70 | 71 | 32 | 37 |
| Average size ($D_{50}$) | | 0.236 | 0.23 | 0.23 | 0.241 | 0.228 | 0.211 | 0.232 | 0.236 | 0.232 | 0.419 | 0.383 |

The AFS Grain Fineness Number (GFN) ranges from 64–79 and the average size ($D_{50}$) of sand is from 0.211–0.241 mm (Table 2). For Ref 1 and Ref 2 sand, GFN is from 32–37 and the average size ($D_{50}$) is from 0.383 to 0.419 mm. The recommended GFN for casting non-ferrous metals should be in the range of 36 to 90 [18].

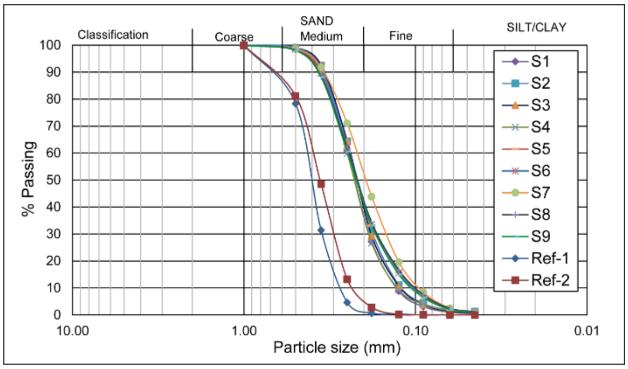

Fig. 4. Particle size distribution curves of sand specimen

Brown [16] noted that the average size of foundry sands generally ranges from 150–400 μm, where 220–250 μm being the most commonly used. The GFN and average size of sands from the Brahmaputra River are consistent with the values quoted by Brown [16], and Burns [18], and this gives good surface finish during casting of non-ferrous metals at low binder levels when making moulds. However, the variation of GFN along with average grain size is slight among the analyzed specimens; thus, the variation is due to the deposition of sediment all year around flowing of the Brahmaputra River.

## 3.4. Thermal analysis by TG-DSC

The thermal decomposition nature of the Brahmaputra River sand was determined by TG-DSC analysis. The weight loss as a function of temperature was measured from a thermogravimetric (TG) curve, and phase transitions were obtained from a differential scanning calorimeter (DSC). A small quantity (<10 mg) of sand sample was subjected to heating approximately 50 °C to 1000 °C at a rate of 20 °C/min under a constant flow of nitrogen gas, at the rate of 20 ml/min. Thermogravimetric (wt%), DSC (heat flow endo down) and ΔT endo down curves for the sample of S1, S4, S7, S9, Ref 1, and Ref 2 under an inert nitrogen atmosphere is presented in Figure 5a, b, c.

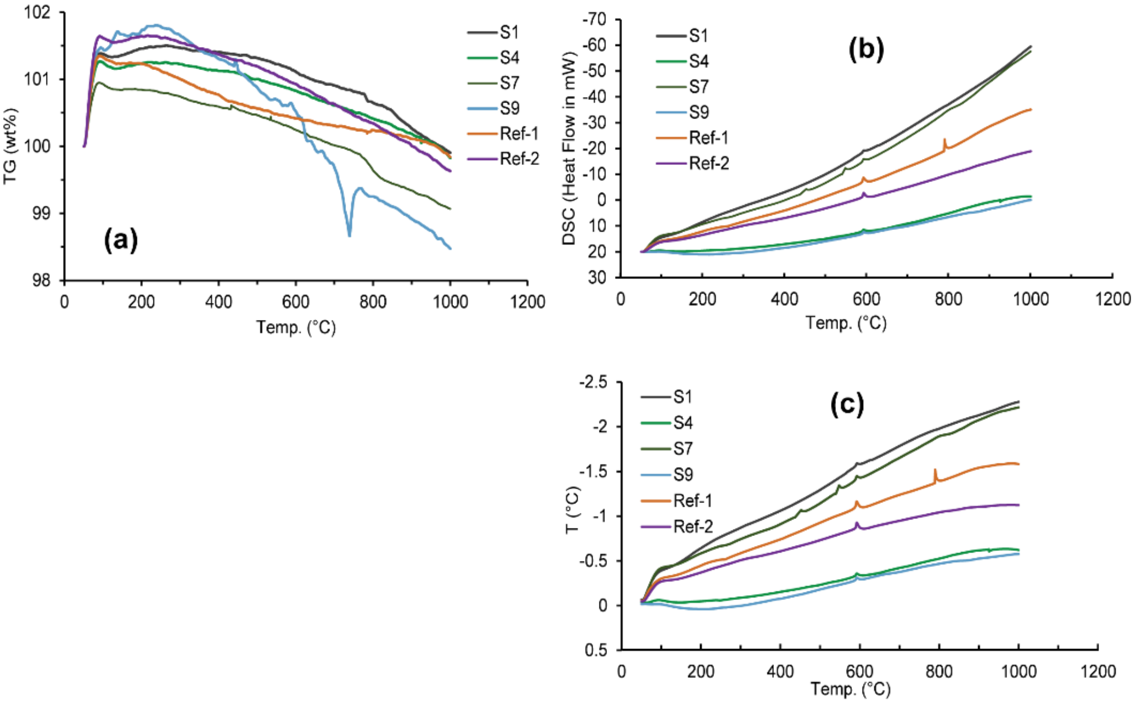

Fig. 5. Thermogravimetric and thermal analysis of sand specimen (a) TG, (b) DSC, (c) ΔT curves

The mass loss determined from the TG (wt%) curve during heating from 50 °C to 1000 °C was ≤ 2% for all samples (Fig. 5a). DSC and ΔT analysis determined from heat flow endo down curve and change in temperature (Fig. 5b, c) respectively during the heating process, which showed quartz inversion at around 574 °C (endotherm peak) for all analyzed samples. This indicates reversible change in the crystal structure, which is the polymorphic transformation of α-quartz to β-quartz [19]. Moreover, the ΔT endo down curves for all samples show a similar trend to the DSC curves. The trend of DSC and ΔT curve (Fig. 5b, c) indicate the thermal stability of the studied sand, which is consistent with Ref 1 and Ref 2 sand. The experimental result depicts that the mass loss of Brahmaputra River sand samples as well as reference sample (Ref 1 and Ref 2) are almost similar in nature, which is very low (≤ 2%). This implies that the studied sand can be used for multiple thermal cycles, i.e., it is reusable. From the above discussion, it may be assumed that the Brahmaputra River sand possesses a low thermal expansion nature and it is thermally stable within 1000 °C temperature and thus, it is suitable for non-ferrous metal casting within this temperature range.

## 3.5. Moulding properties of sand

A good quality green sand mould is the prerequisite for the best metal casting medium. The moulding sand is characterized by a combination of foundry testing, which is discussed here. The results of green moulding sand properties (green strength, permeability, hardness, compactability, flowability, and shatter index) along with bulk density, loss-on-ignition (LOI), specific gravity, clay content, pH, and ADV of Brahmaputra River sand are given in Table 3. Besides, available standard values of the investigated parameters are shown in Table 3 for comparison. The green compression (GCS) and shear strength (GSS) are regulate the mouldability of a sand mixture, which ranges between 17.95–24.32 kN/m$^2$ and 14.02–19.12 kN/m$^2$ respectively (Table 3). The green compression strength value should be 10.34 kN/m$^2$ or more for a sand mixture to be mouldable [16]. For high silica content sand e.g., Ref 1 and Ref 2 sample, the slightly greater GCS and GSS results obtained which ranges from 25.50–29.58 kN/m$^2$ and 19.81–23.21 kN/m$^2$ respectively. Brown [16] mentioned that the green strength of sand for iron foundries typically ranges from 70 to 100 kN/m$^2$, whereas, Jain [20] noted the value of 59–78 kN/m$^2$ for ferrous and non-ferrous metal casting. In the present study, the green strength is lower than the values quoted by Brown [16] and Jain [20] which could be due to the specimen handling during the execution of test; yet it might be suitable for non-ferrous metal casting. The obtained strength values of Brahmaputra River sand might be prevent defects, unsound casting, incomplete molten metal flow, rough surfaces, etc. However, Sahoo [2] pointed out that the strength given by 10% bentonite (binding agent) mixed with moulding sand is suitable to achieve desirable strength in foundry sand. Therefore, the obtained strength properties of sand for 10% bentonite are comparatively high, which is sufficient for foundry mould preparation without distortion or collapse even after the pattern has been removed from the moulding box. Moreover, 10% bentonite keeps the sufficient reusability of sand.

Table 3.
Moulding and other properties of the analyzed river sand

| Sample Id. | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | Ref 1 | Ref 2 | Standard value [16, 17, 20] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Green compression strength (GCS), kN/m$^2$ | 19.32 | 19.52 | 24.03 | 23.83 | 17.95 | 24.32 | 20.30 | 21.87 | 22.56 | 29.58 | 25.50 | 49-78 |
| Green shear strength (GSS), kN/m$^2$ | 15.20 | 15.30 | 18.63 | 18.53 | 14.02 | 19.12 | 15.98 | 17.06 | 17.65 | 23.21 | 19.81 | - |
| Compactbility, % | 37 | 37 | 39 | 43 | 38 | 46 | 40 | 43 | 45 | 59 | 54 | 38-52 |
| Green hardness | 78 | 77 | 81 | 79 | 79 | 83 | 82 | 83 | 85 | 82 | 81 | 70-85 |
| Flowability, % | 53 | 51 | 55 | 51 | 59 | 58 | 56 | 61 | 62 | 57 | 61 | - |
| Air permeability number (Pn) | 156 | 159 | 157 | 149 | 154 | 132 | 148 | 141 | 139 | 131 | 128 | 40-150 |
| Bulk density of green sand, gm/cc | 1.54 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1.83 | 1.72 | - |
| Shatter index, % | 46.71 | 45.52 | 43.13 | 43.55 | 46.88 | 44.12 | 46.27 | 42.72 | 45.66 | 47.36 | 41.94 | - |
| Bulk density of silica sand, gm/cc | 1.23 | 1.45 | 1.40 | 1.46 | 1.40 | 1.38 | 1.45 | 1.35 | 1.46 | 1.72 | 1.64 | 1.49 |
| LOI, % | 0.16 | 0.14 | 0.15 | 0.16 | 0.14 | 0.14 | 0.13 | 0.15 | 0.13 | 0.17 | 0.24 | Max. 0.5 |
| Specific gravity | 2.59 | 2.54 | 2.64 | 2.67 | 2.61 | 2.63 | 2.58 | 2.62 | 2.56 | 2.66 | 2.63 | 2.65 |
| Clay content (<45 μm), % | 0.81 | 0.84 | 1.28 | 1.04 | 1.88 | 2.45 | 1.92 | 1.67 | 1.86 | 0 | 0 | Max. 0.5 (<20 μm) |
| pH | 7.9 | 7.5 | 7.2 | 7.3 | 7.4 | 7.2 | 7.3 | 7.4 | 7.2 | 6.9 | 7.1 | 6.9-7.1 |
| Acid Demand Value (ADV), ml | 6.3 | 5.9 | 4.7 | 4.9 | 5.8 | 5.4 | 4.1 | 5.8 | 4.7 | 4.2 | 4.4 | 6 |

The compactability and green hardness of studied river sand lie between 37–46% and 77–85 respectively, although the same values for Ref 1 and Ref 2 sands ranges from 54–59% and 81–82, respectively. According to Brown [16], the compactability value of green sand for iron foundries is 45–52%, which is consistent with the obtained compactability result (Table 3). Rao [17] mentioned the mould hardness 70-85 for casting of non-ferrous metals, which is well in agreement with the present analysis. Besides, the flowability result is highly analogous to the reference sand and it is in the range of 51% to 62%, whereas for Ref 1 and Ref 2 sands, the flowability lies between 57–61%. The flowability results indicate that the analyzed sand is subangular to subrounded shape of grain, hence more angular sands have lower packing density and poorer flowability [16]. The compactability, green hardness and flowability values might be suitable for non-ferrous metal casting [18]. The air permeability number ranges from 132 to 159 with an average of 148, whereas for Ref 1 and Ref 2 sands, permeability lies between 128 and 131 (Table 3). The higher the number, the higher the permeability of mould, and this permeability is affected by the sand type, particle size, and binder content [21].

The air permeability number of Brahmaputra River sand is slightly higher than the reference sand and also greater than the recommended permeability values (80–110) of green sand for iron foundries [16]. However, it is in well agreement with the permeability number (100–150) described by Jain [20], which is beneficial for non-ferrous casting. During casting, high air permeability helps to escape the hot air within the sand mould by avoiding gas defects in castings. This higher permeability of moulding sand is beneficial for high-pouring temperature metals [17]. The bulk density of river sand (1.23–1.46 gm/cc) and green sand (1.54–1.55 gm/cc) shows a consistency of result (Table 3). The bulk sand density and green sand density of reference sand (Ref 1 and Ref 2) range from 1.64–1.72 gm/cc and 1.72–1.83 gm/cc, where those values are slightly higher than the studied sand. Brown [30] mentioned that the density for loose silica sand is 1.49 gm/cc, whereas for moulding medium (green sand), when compacted in the mould the density is 1.5 gm/cc. The density values of present study are partially consistent with the values quoted by Brown [16].

The shatter index value (42.72–46.88%) is optimum for foundry application, which enable to keep the shape of the mould during pattern withdrawal/lift by resisting impact [17]. For Ref 1 and Ref 2 sand, the shatter index value is 47.36% and 41.94%, respectively, which is consistent with the Brahmaputra River sand. The Loss-on-ignition (LOI) value for analyzed river sand ranges from 0.13 to 0.16%, whereas the reference sand (Ref 1 and Ref 2) show a value of 0.17% and 0.24%, respectively (Table 3), which is consistent with the test of TG-DSC. This mass loss (LOI) implies weight loss due to generation of gas, loss of chemically bound water, and some weight gain due to oxidation if the test is not done under an inert atmosphere [21]. The LOI for typical foundry silica sand is <0.5% [16]. The obtained value of LOI is lower than the typical silica foundry sand. This lower LOI is beneficial as the temperature rapidly increases in foundry sand during pouring the liquid alloy into the cavity [22]. The LOI value signifies that the specimen is free from impurities (i.e., organic or other gas-forming materials) and possesses the high heat absorption capability with high refractoriness, and thus the sand sample is suitable for making mould. The specific gravity value ranges from 2.54–2.67, which is consistent with the Ref 1 (2.66), Ref 2 (2.63) sample, and also the reference value for quartz sand (for pure quartz grains, 2.65 [23]). According to Brown [16], the specific gravity of silica sand (2.65) is lower than the other non-silica sands (zircon, chromite, and olivine). The specific gravity value of the studied samples is consistent with the Brown [16] statement.

The clay content (<45 μm) of Brahmaputra River sand ranges from 0.81% to 2.45%, with an average of 1.53%, which is slightly higher than Brown's [16] recommended value (maximum 0.5%). Brown [16] considered less than 20 μm sized particles as clay; this might be the cause for this marginally higher clay content (clay size is <45 μm in this study). This non-binding clay has no effect on the moulding properties of sand. The sand can be readily used in non-ferrous metal casting directly after sieving [17]. The pH and ADV of the Brahmaputra River sand range from 7.2–7.9 (average 7.4) and 4.1–6.3 ml (average 5.3) respectively, although pH and ADV for Ref 1 and Ref 2 sand are 6.9–7.1 and 4.2–4.4 ml respectively. There is a close consistency of pH value with de Hoyos-Lopez et al. [24] findings. On the other hand, Brown [16] mentioned that the maximum ADV for sand is 6 ml, and the ADV result of Brahmaputra River sand is less than 6 ml except for sample S1 (Table 3). The pH and ADV of analyzed samples are in well agreement with the chemical composition results (Table 1), and can be facilitated during moulding and casting without adverse impact of binders for non-ferrous metal casting.

## 3.6. Metal casting trial

An attempt has been made to trial metal casting by using Brahmaputra River sand and the commercial silica foundry sand for as-cast properties comparison. The casting trials of non-ferrous metals (e.g., aluminum, zinc) have been accomplished in the laboratory (Fig. 6). The mould was prepared by using a mixture of 83% river sand, 10% bentonite clay, 2% graphite, and 5% water.

Aluminum and zinc alloy casting were completed separately, using both types of sand as mentioned above, and the FESEM photomicrographs were taken, which are shown in Figure 7. The casting product quality is determined based on the casting porosity by the bulk density measurement method, and the microstructural analysis from the FESEM image. The volumetric casting porosity of aluminum alloy was 2.35%, whereas for zinc alloy it was 2.47% for as-cast product from the Brahmaputra River sand mould, which indicates good quality casting products. Furthermore, the porosities of the as-cast products of aluminum and zinc alloys measured using commercial silica foundry sand are 2.19% and 2.31%, respectively, indicating that the porosities of the as-cast products from both sand moulds are nearly similar.

Microstructurally, both alloys (aluminum and zinc) have a different texture with a comparatively better surface finish (Fig. 7). A clear microstructure was observed from the FESEM image in Figure 7.

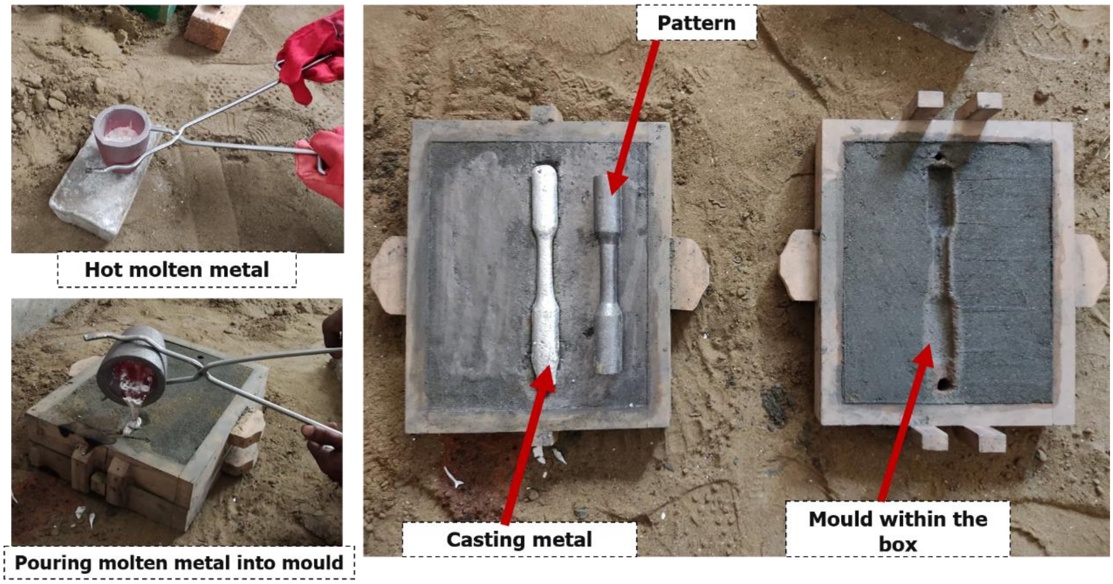


Fig. 6. Processes of casting using river sand as a mould material

A dendritic pattern for aluminum casting (Fig. 7a, c) and a mosaic compositional pattern for zinc alloy (Fig. 7b, d) were observed [25, 26]. Apart from this, microstructurally comparing the as-cast product from the Brahmaputra River sand (Fig. a, b) and the commercial silica foundry sand (Fig. c, d) shows relatively identical texture. Finally, it seems that the analyzed Brahmaputra River sand exhibits satisfying foundry properties for non-ferrous metal casting (e.g., aluminum, zinc) obtained from casting trials. Thus, the sand samples are suitable for making a mould for any pattern.

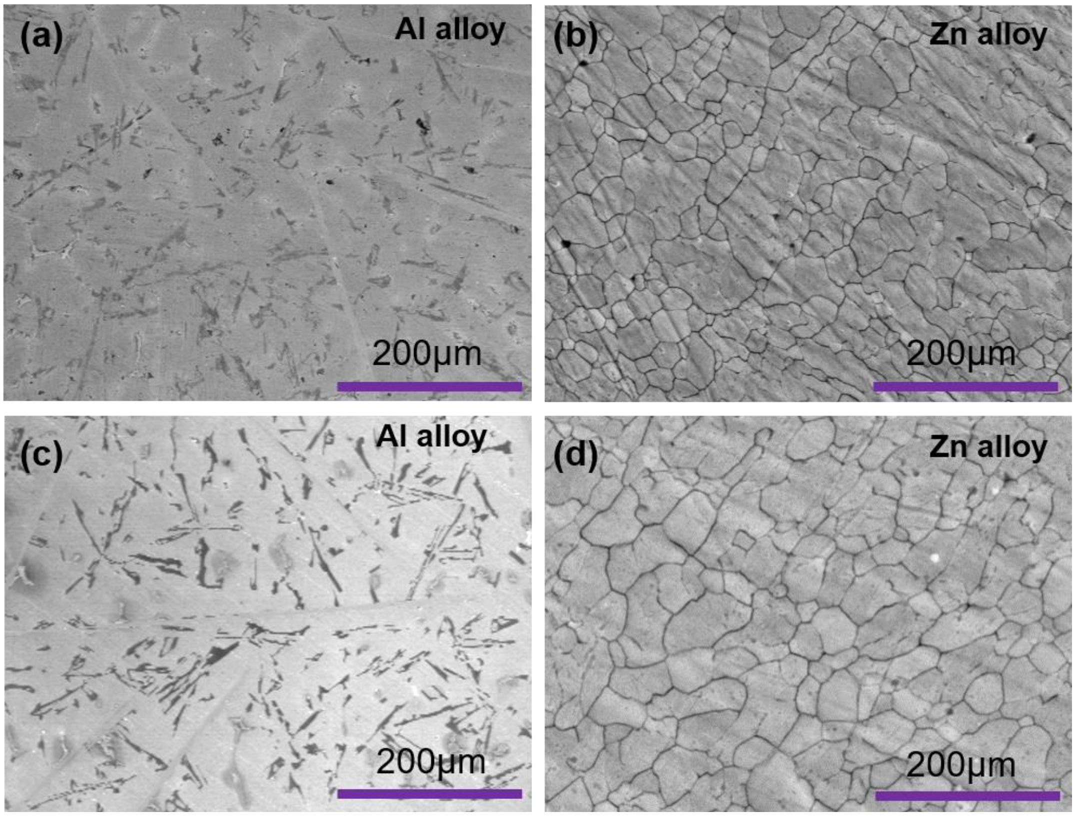


Fig. 7. Surface texture and microstructure of alloys using Brahmaputra River sand (a and b) and commercial silica foundry sand (c and d)

# 4. Conclusions

The following points can be summarized by an evaluation of the foundry properties of the Brahmaputra River sand, Bangladesh:

- The sand is characterized by light grey color, friable, medium to fine particle size with narrow distribution, AFS GFN 64–79 and average size of sand ranges from 0.211–0.241 mm.
- The sand is mainly composed of quartz, some feldspar, amphibole, chlorite, and mica, as obtained from microscopic analysis and XRD. Chemical study (XRF) reveals that the sand is dominated by $SiO_2$ (67.81–69.97%) with $Al_2O_3$ (12.12–13.45%), $Fe_2O_3^t$ (6.0–6.47%), CaO (3.36–3.74%) and minor quantities of other oxides (<1.0%).
- The green strength result might be satisfactory for foundry mould preparation for non-ferrous metal casting without distortion or collapse, and likely it prevent defects, unsound casting, incomplete molten metal flow, and rough surfaces, etc. Moreover, the compactability, green hardness, and flowability values indicate its suitability for non-ferrous metal casting. The air permeability number also lies within the recommended value of green sand, which might help to escape the hot air within the sand mould by avoiding gas defects in castings. Further, the shatter index value is optimum for foundry applications, which may enable to keep the shape of mould during pattern withdrawal/lift. The comparatively lower LOI value signifies that the specimen is free from impurities, which is consistent with the TG-DSC result. The pH and ADV of analyzed samples are in well agreement with the chemical composition results.
- The foundry properties of the analyzed samples are consistent to some extent with the properties of reference/benchmark sand (Ref 1 and Ref 2) as well as standard values from literature and are suitable for non-ferrous metal casting by providing optimum strength, permeability, compactability, flowability, etc.
- Despite having an ordinary chemical composition, the sand is suitable for casting non-ferrous metals, as evidenced by the high quality output from casting experiments of aluminum and zinc alloys.

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# Conflict of interest

The authors declare that they have no conflict of interest.

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