



# A sustainable utilization of waste foundry sand in soil stabilization: a review

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## Abstract

Soil stabilization involves various techniques and processes to improve the properties of soil especially expansive soils as it is considered troublesome for civil engineering and other field works due to its diminished strength shrinkage and swelling properties. Therefore, it becomes imperative to inculcate certain traditional or non-traditional stabilizers to elevate the geotechnical properties of soil. Waste foundry sand is one such non-traditional stabilizer that has been utilized in the soil for the improvement of soil properties. This paper presents an overall review of the past studies carried out on soil stabilization using waste foundry sand. The results reveal Atterberg's limits, i.e., liquid limit; plastic limit decreases with the increase in the percentage of waste foundry sand in the mix. Specifically, the liquid limit undergoes a reduction within the range of 25–30%, while the plastic limit experiences a decrease within the range of 16–18% when the optimum percentage of waste foundry sand (20–30%) is added to expansive soils. Further, there is an increase of around 25–42% in unconfined compressive strength and around 50–80% in California bearing ratio values on adding optimum percentage of WFS. Therefore, a WFS content of 20–30% is recommended as the optimum choice for soil stabilization in clayey soils.

**Keywords** Expansive soil · Waste foundry sand · CBR test · UCS test · SEM analysis

## Introduction

The majority of buildings built on expansive soils endure significant settlements as a result of volumetric changes caused by changing water content. The expanding soil volumetric changes are difficult to forecast exactly since each clay particle is controlled by surface physiochemical processes. Due to the tiny particle size of the clay and the diffused double layer that forms around each particle, these surface physiochemical forces become active, which also contributes to the expansion and contraction of these soils (Guney et al. 2006; Sharma and Hymavathi 2016; Sharma and Sharma 2019; Taye and Araya 2015). To improve the geotechnical properties of the soils (load carrying capacity,

permeability, potential towards swelling, and sensitivity to change moisture content), various methods are used (Harichane et al. 2011; Koliass et al. 2005). The soil improvement techniques include soil stabilization, mechanical remediation, grouting, soil reinforcement, addition of geo textiles, geo membranes, and graded aggregate materials (Amakye and Abbey 2021). However, the methods adopted to improve the properties of expansive soils are quite expensive and, as a result, are hardly used in the construction of highways across expansive soils in developing countries. Therefore, it is necessary to discover a low-cost alternative technique to improve geotechnical properties of expansive soils (Taye and Araya 2015). Nonetheless, soil stabilization is considered one of the simplest and easiest approach to enhance the properties of soil. Soil stabilization refers to the process of improving various geotechnical characteristics of soil to meet specific project requirements or to enhance its performance under load, weather, or environmental conditions (Harichane et al. 2011; Koliass et al. 2005). In an effort to improve the geotechnical properties of soil and in order to meet the requirements of stabilization that can increase the bearing capacity, soil stabilization is adopted which involves the process of combining soil with certain materials (Bozbey

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and Garaisayev 2010). Various soil stabilization techniques such as mechanical, chemical, polymer stabilization, bituminous stabilization, and enzyme stabilization are usually adapted to address the issues associated with expansive soils (Ikeagwuani and Nwonu 2019).

With the increase in the population, waste production both grows in quantity and type and hence large amounts of various wastes are produced as a byproduct of various industries, including industrial, agricultural, and municipal waste. If not disposed of properly, these waste products could be dangerous to the environment due to their hazardous effects (Anupam et al. 2013; Sharma and Sharma 2019, 2020). Therefore, it becomes imperative to utilize these wastes in soil as these wastes help to enhance the geotechnical properties and minimize the problems related to its disposal (Anand et al. 2021; Deng and Tikalsky 2008; Javed and Lovell 1994; Siddique and Singh 2011; Sharma and Sharma 2021a, b).

## Foundry sand

Foundry sand is a byproduct obtained from production of ferrous and non-ferrous metal industries. Owing to its favorable heat conductivity, it has been utilized as a moulding and casting material for various purposes. Sand has been used for a variety of foundry procedures, and many binders and additives are added to it to improve its characteristics. Foundry sand is divided into two groups based on the type of binder used: chemically bonded and clay-bonded (green) sand (Siddique 2007). Green or clay-bonded sand uses clay as a binder, whereas chemically bonded sand uses binders made of chemicals. Green foundry sand typically contains 85 to 95% silica sand, 4 to 10% bentonite clay as a binder, and 2 to 10% carbonaceous elements, small amounts of oxides like magnesium oxide (MgO), potassium dioxide (K<sub>2</sub>O), and titanium dioxide (TiO<sub>2</sub>) to promote casting surface finishing. In contrast, chemically bonded sand, also known as foundry sand comprises 93–99% silica sand and just 1–3% chemical binder. The foundry sand mostly utilized as “green sand” (clay-bonded) consists of silica sand, around 10% bentonite clay, and 2 to 5% water and sand that has been chemically bound typically contains 97% silica sand (Winkler and Bolshakov 2000). About one tonne of waste foundry sand is produced for every tonne of molten metal (McIntyre et al. 1992). Sand has been used in the manufacturing of moulds and cores in the foundry industry for a number of reasons, including its availability practically anywhere, low cost (Javed and Lovell 1994). Foundry sand is a non-hazardous material used in several industrial sectors especially in construction and civil engineering works. The foundry sand is generally recycled and reused through numerous production cycles; hence it becomes unsuitable for industrial

purposes after recycling it two to three times and pile up as a waste material. Furthermore, this waste material is utilized in soil to improve its properties (Tittarelli 2018). More than three million tonnes of metal castings were manufactured in Brazil in 2008, and the country’s waste foundry sand production has significantly increased in recent years resulting in increased need for new sanitary landfills; hence reusing waste foundry sand (WFS) becomes a crucial issue for the foundry industries and for the protection of the environment (Noronha Marques et al. 2023).

A lot of efforts have been made to utilize waste foundry sand in civil engineering projects. The sand meets the requirements for usage as an aggregate in asphalt concrete (Javed and Lovell 1994), concrete products (Bhardwaj et al. 2021; Guney et al. 2010; Naik et al. 1994; Sharma and Sharma 2019), flowable fills (Deng and Tikalsky 2008), and pavement bases and subbase courses (Fox and Mast 1998; Kleven et al. 2000; Partridge and Alleman 1998). According to investigations, bentonite and clay-bound foundry sands can be used as an aggregate in base and subbase courses beneath flexible pavements because of their adequate mechanical characteristics (Abichou et al. 2000; Anand et al. 2021; Goodhue et al. 2001; Kleven et al. 2000; Sharma and Sharma 2020). In addition, the soil stabilized with the waste foundry sand lowers the possibility of environmental degradation (Abichou et al. 2000). Studying and evaluating the effects of foundry sand on expansive soil yielded the conclusion that fine foundry sand, which has high silica content, may be used to stabilize soil as the addition of foundry sand increases California bearing ratio (CBR) value (Ahmad et al. 2021). With the addition of 40% foundry sand, CBR value increased resulting in the achievement of the required maximum dry density. The use of foundry sand, fly ash, and tile waste in clayey soils improved the characteristics of the soil when used in a proportion of 10 to 50% with a 10% increment, and when all three elements were added to the soil, the CBR value increased from 2.43 to 7.35% revealing that the combination may be used to build subgrades for low-traffic roadways (Kumar et al. 2016). The maximum dry density and California bearing ratio values of the soil foundry sand mixture were found to increase with the addition of foundry sand in clayey soil initially up to a certain value, but on further addition of foundry sand in clayey soil, the values of maximum dry density and California bearing ratio showed a decreasing trend (Mishra 2014). The unconfined compressive strength of the soil was increased up to 20.07% when the foundry sand containing 2.5% silica sand and 7.5% dust sand foundry sand were added. This demonstrated the advantages of using an alloy of silica sand and dust silica sand as clay stabilizer additive (Nuryati et al. 2023).

### Physical properties of foundry sand

Foundry sand is generally subgranular to round in shape and mainly contains silica but the silica content found in foundry sand is less than that of regular sand (Aneke and Shabangu 2021). The physical properties of foundry sand vary depending on the various factors such as type of casting process, type of additives added to foundry sand during moulding process, the place from which foundry sand is originated. The size of its particles is usually less than 100 micro-meters (Aneke and Awuzie 2018). The fineness modulus of foundry sand usually lies in the range of 0.96–1.6 whereas for normal sand it is in the range of 2.3–3.1. The grain size distribution is generally uniform (Prabhu et al. 2014). The specific gravity lies in the range 2.16–2.72, and the absorption values of foundry sand vary widely because of the presence of additives in it. The use of materials such as clay saw dust in moulding process is still carried out as it reduces the density of materials and hence enhances the soil properties (Bhardwaj et al. 2021; Dungan et al. 2006). The physical properties of waste foundry sand studied by various researchers are shown in Table 1.

### Chemical properties of foundry sand

The chemical composition of waste foundry sand is dependent on the type of metal that has been cast at the foundry, as well as the type of binder and combustible utilized. The chemical nature of the foundry sand may have an effect on how it performs. The primary component of waste foundry sand is silica sand coated with a thin layer of burnt carbon, residual binder (bentonite, sea coal, resins/chemicals), and dust (Moses et al. 2013). The pH value of waste foundry sand may vary somewhere around 4 to 8 and is usually dependent on the binder and type of cast metal. As silica sand is hydrophilic, it attracts water to its surface (Johnson 1981). As a result of the presence of phenols in foundry sand, it has been noted that some waste foundry sands can be corrosive to metals. There is considerable concern that precipitation that percolates through stockpiles could mobilize leachable fractions, leading to phenol discharges into surface or ground water systems. The sources and stocks of foundry sand must be monitored to assess the necessity for phenol discharge restrictions (Eko and Riskowski 2001; Osinubi et al. 2015; Sujjavanidi and Duangchan 2004). The chemical composition of a typical sample of waste foundry sand is listed in Table 2.

**Table 1** Physical properties of waste foundry sand

	Ahmad et al. (2022)	Smarzewski (2020)	Manoharan et al. (2018)	Reshma et al. (2021)	Iqbal et al. (2019)	Siddique et al. (2010)	Kaur et al. (2012)	Deng and Tikalsky (2008)	Basar and Aksoy (2012)
Specific gravity	2.34	2.45	2.36	2.3	2.65	2.47	2.16	2.72	2.10
Density (KN/m <sup>3</sup> )	1.54	1.52	1.81	1.72	1.81	2.58	2.25	1.83	1.44
Water absorption (%)	4.08	1.40	0.90	1.2	1.48	0.9	1.3	1.34	1.2
Fineness modulus	2.33	5.92	2.37	2.66	3.06	3.2	2.07	2.76	–
Moisture content (%)	3.25	–	0.60	–	–	5.1	3.7	4.85	2.17

**Table 2** Chemical properties of waste foundry sand

Constituent value (%)	Guney et al. (2010)	Siddique and Singh (2011)	Smarzewski (2020)	Ahmad et al. (2021)	Prasad et al. (2018)	Bilal et al. (2019)	Guney et al. (2010)	Dogan et al. (2018)	Bhardwaj and Sharma (2020)
Silica (as SiO <sub>2</sub> )	98	83.8	95.3	81.8	88.11	88.5	98	98.64	84.90
Aluminum (as Al <sub>2</sub> O <sub>3</sub> )	0.8	0.81	1.9	6.9	0.49	4.63	0.8	0.74	5.21
Iron (as Fe <sub>2</sub> O <sub>3</sub> )	0.25	5.39	0.7	2.3	2.38	0.83	0.25	1.01	3.32
Potassium (as K <sub>2</sub> O)	0.04	1.14	–	0.9	0.83	0.01	0.04	0.21	0.97
Calcium (as CaO)	0.035	1.42	0.35	3.55	1.65	0.90	0.035	0.35	0.58
Magnesium (as MgO)	0.023	0.86	–	0.32	0.76	0.21	0.023	0.50	0.67
Sulphur (as SO <sub>3</sub> )	0.01	0.21	–	–	–	–	–	–	0.29
Sodium (as Na <sub>2</sub> O)	0.04	0.87	–	0.6	0.95	0.02	0.04	1.07	0.50

## Applications of waste foundry sand in various fields

### In concrete industry

Waste foundry sand can be used as a substitute for natural sand in construction materials such as concrete, asphalt, and masonry products. Incorporating foundry sand in concrete mixtures can improve strength, durability, and workability (Yazoghli-Marzouk et al. 2014). The inclusion of 9% lime, 20% waste foundry sand (WFS), and 10% molasses has proven to be satisfactory in enhancing the workability of clayey soil. Therefore, a WFS content of 20% is recommended as the optimum choice for soil stabilization in clayey soils (Sharma and Sharma 2020).

### In road construction

Foundry sand can be used as a base or subbase material in road construction and pavement projects. It can help enhance the stability, drainage, and load-bearing capacity of the road surface (Miguel et al. 2012). The geotechnical testing results indicate that incorporating 21% waste foundry sand (WFS) and 6% sodium chloride (NaCl) is deemed suitable for designing subgrades intended for low-volume flexible pavements (Altaf et al. 2023).

### In soil stabilization

Foundry sand can be used for soil stabilization purposes in construction projects, especially in areas with poor soil quality or high erosion potential. It helps improve soil compaction, stability, and permeability (Siddique and Singh 2011). Additionally, UCS and CBR tests conducted on clayey soil revealed that the inclusion of 40% WFS content yields higher MDD, UCS, and CBR compared to other mixtures (Kumar et al. 2016).

### In manufacturing industry

Waste foundry sand can be used as a raw material or additive in various manufacturing processes, such as in the production of bricks, ceramics, and refractory materials. It can provide cost savings and reduce environmental impact compared to using virgin materials (Tittarelli 2018).

### In environmental remediation

Foundry sand can be used in environmental remediation projects, such as land reclamation, mine reclamation, and brownfield redevelopment. It can help restore disturbed or

contaminated land while providing a sustainable disposal option for the waste material (Klinsky et al. 2016).

### In construction projects as fill material

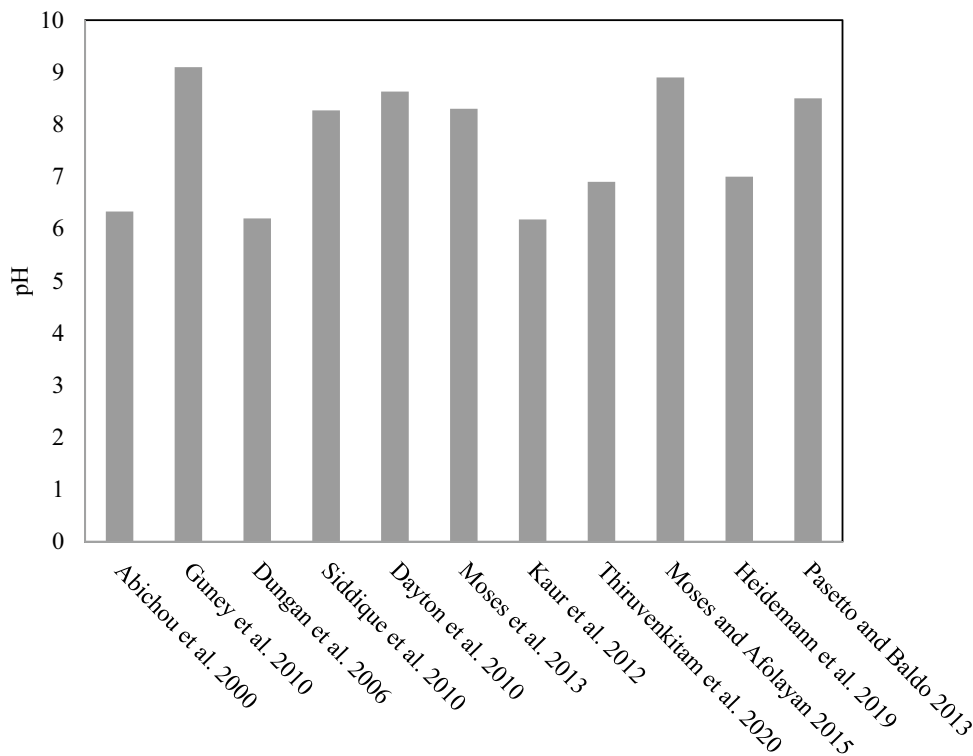
Waste foundry sand can be utilized as an alternative fill material in construction projects, such as in embankments, backfilling, and landfills. It can reduce the demand for virgin fill materials and alleviate pressure on natural resources (Zhang et al. 2021).

## Results and discussions

### pH value

Foundry sand is primarily a mixture of sand and bentonite moreover its hydraulic properties are similar to that of sand and bentonite mix. The variation in pH of foundry sand may be due to type of metal that has been casted in a particular foundry. Figure 1 shows the variation of pH of foundry sand collected from different locations by various researchers. The samples of foundry sand were consigned to the university of Wisconsin–adison having a pH of 6.33 (Abichou et al. 2000). The foundry sand used in this research was acquired from US Silica (Berkeley) and was specifically graded for the use of moulding sand owning a pH of 6.2 (Dungan et al. 2006). The foundry sand used was collected from Toprak Foundry in Bilecik, Turkey with a pH of 9.1 (Guney et al. 2010). The foundry sand was gathered from states of Central and Eastern USA with a pH of 8.63 (Dayton et al. 2010). The work has been carried out on improvement of soil properties using waste foundry sand having a pH of 8.9 (Moses and Afolayan 2011). The waste foundry sand utilized in this research was a byproduct of iron casting industry for auto parts in the city of Joinville, Southern Brazil. The sample of foundry sand used had a sandy texture and a pH of 7 (Heidemann et al. 2021). The foundry sand consisted silica sand covered with thin film of carbon and other oxides having a pH of 8.5 have been utilized in this investigation (Pasetto and Baldo 2015). Foundry sand used in this study has been coated with a thin film of burnt carbon, residual binder dust with a pH value of 8.27 (Siddique et al. 2010). Sample of WFS was collected from a foundry in Coimbatore, India, and was kept in polyethylene bags having a pH value of 6.9 (Thiruvekitam et al. 2020). The addition of WFS during soil stabilization typically has a neutral to slightly alkaline effect on the pH of the material it is combined with. This is because foundry sand is generally composed of silica sand and various binding agents, which alter the pH of the soil. However, the specific pH impact can also depend on the composition of the soil and any additives used in conjunction with the WFS during stabilization. In some cases,

**Fig. 1** pH values of foundry sand obtained from various locations

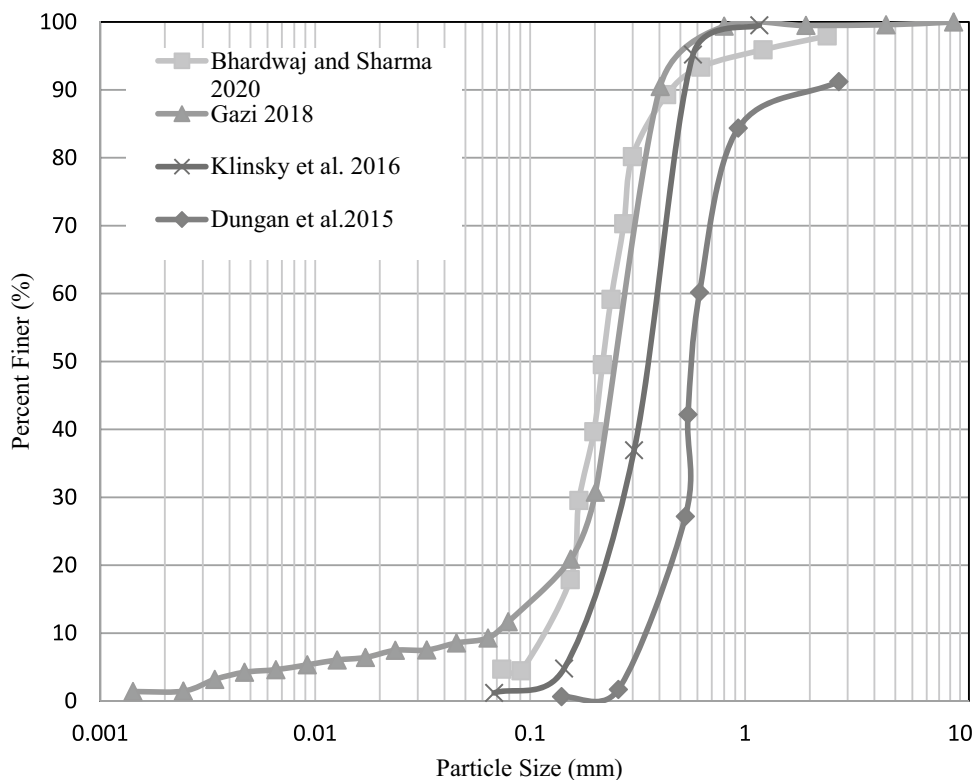


if the WFS contains residual chemicals or additives from the foundry process, it may have a slightly acidic or alkaline effect on the soil pH (Heidemann et al. 2021; Eko and Riskowski 2001; Moses and Afolayan 2011).

**Grain size distribution curve**

Figure 2 shows the particle size distribution curve of soil containing waste foundry sand by various authors.

**Fig. 2** Grain size distribution of waste foundry sand by various researchers



According to USCS and AASTHO classification, soil containing 60% WFS and 70% WFS are expected to have a similar performance as that of SM-SC and A-4 to A-2-4 respectively and hence can be used in subgrade soil (Klinsky et al. 2016). Foundry sand consists of green sand and coarse sands. The grain size distribution of these materials was determined by pipette analysis and sieving. The soil particles were ground to individual particles using mortar and pestle. The novolac resin-coated sand was used before thermosetting and did not require grinding. Green sands passed through a 0.5-mm sieve prior to soil blending (Dungan et al. 2006). The purpose of particle size distribution is to find relative proportions of each size range and classification of soil. According to this study, the percentage of coarser particles was equal to 87% and percentage of fines was equal to 13%. Furthermore, in accordance with AASHTO classification, WFS may be considered as A-2-4 soil type (Gazi 2018).

### Swell potential

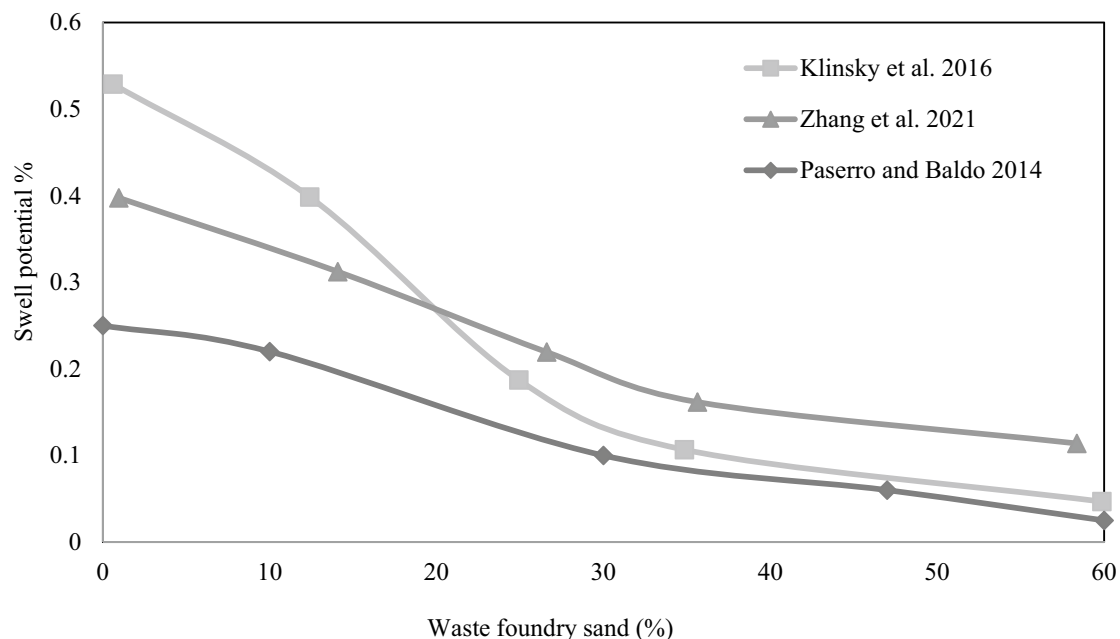
Figure 3 depicts the relationship between swell potential and varied percentage of foundry sand. Shrink-swell behavior of expansive subgrade soils is the major cause of pavement defects causing movement and differential settlement in the pavement. With the increase in the percentage of waste foundry sand from 0 to 60%, the swell potential of soil decreased from 0.60 to 0.04% (Klinsky et al. 2016). Studies had shown an improvement in the swell and shrinkage properties of expansive subgrade when waste foundry sand was added in varied proportions. The swell potential has been

reduced from 0.14 to 0.02% on addition of waste foundry sand from 0 to 60% to it (Pasetto and Baldo 2015). As the proportion of waste foundry sand increased from 0 to 60%, the swell potential decreased from 0.11 to 0.4% (Zhang et al. 2021). The addition of waste foundry sand to soil increases the percentage of coarse particles and decreases the soil's specific surface area, which tends to limit its swelling potential. Also, the addition of waste foundry sand reduces the swelling potential of soil because non-swelling WFS particles partially replace swelling soil particles (Klinsky et al. 2016; Zhang et al. 2021).

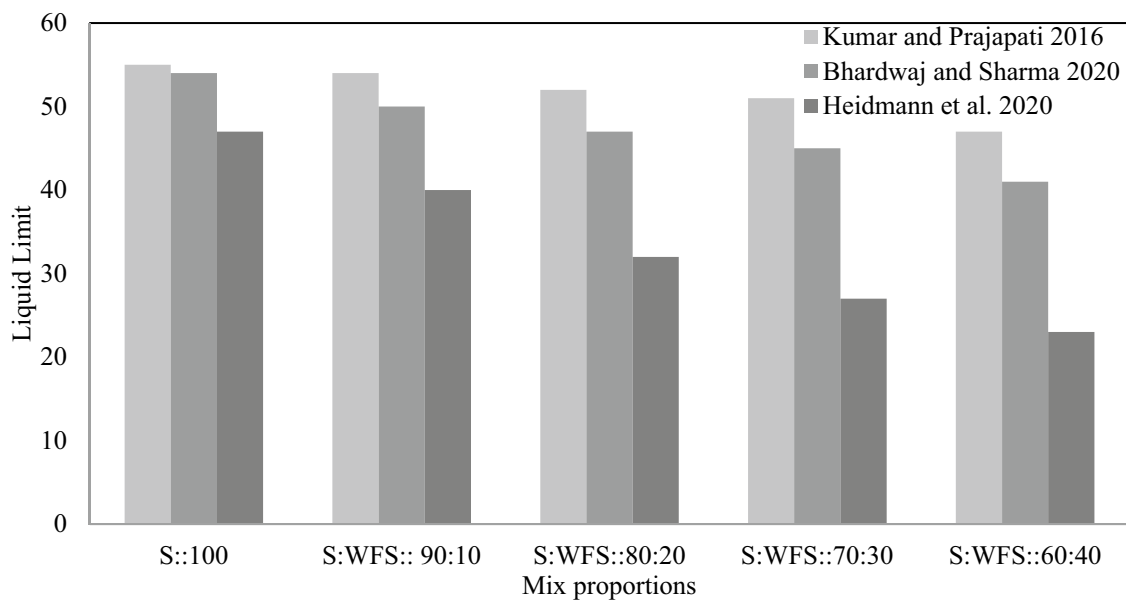
### Consistency limits

Consistency limits are used to find out the consistency of soil at varied moisture content and help to determine the properties of cohesive soil. Figure 4 represents the variation of liquid limit with the increase in the percentage of waste foundry sand. The liquid limit of soil decreased with the increased percentages of waste foundry sand in the mix (i.e., 10%, 20%, 30%, and 40%).

With the increase in the percentage of waste foundry sand in the mix such as 10, 20, 30, and 40%, the percentage decrease in liquid limit was 14.89%, 31.9%, 48.936%, and 51.06% respectively (Heidemann et al. 2021). The percentage decrease in the mix was found to be 7.40%, 12.96%, 16.66%, and 24.07% with the increase in the percentage of waste foundry sand in the mix in varied proportions such as 10, 20, 30, and 40%, respectively (Bhardwaj and Sharma 2020). The liquid limit of soil decreased with the increase



**Fig. 3** Relationship between swell potential and varied percentage of foundry sand



**Fig. 4** Variation of liquid limit with the addition of waste foundry sand in the mix

in the percentage of waste foundry sand. The percentage decrease in the mix was 1.81%, 5.45%, 7.27%, and 14.54% with the increase in percentage of waste foundry sand such as 10, 20, 30, and 40% respectively 55% (Kumar et al. 2011). The reduction in the liquid limit with the increase in the percentage of waste foundry sand may be due to the addition of coarser particles to the soil which are cohesion less in nature. Furthermore, the addition of coarser particles decreases the surface charge which results in the reduction in the amount of absorbed water, thus leads to decrease in the liquid limit (Bhardwaj and Sharma 2020; Heidemann et al. 2021).

Figure 5 depicts variation of plastic limit with the increase in the percentage of waste foundry sand in the mix. With the increase in the percentage of waste foundry sand such as 10, 20, 30, and 40% in the mix, the percentage decrease in the plastic sand was 10.52%, 15.78%, 26.31%, and 42.10% respectively (Bhardwaj and Sharma 2020). The percentage decrease in the plastic limit was 11.11% and 33.33% with the increase in the percentage of waste foundry sand (i.e., 10% and 20%). However, with the further increase in the percentage of waste foundry sand in the mix, the plastic limit did not show any change. Hence, the optimum percentage of waste foundry sand in the mix was 20% (Heidemann et al. 2021). With the increase in the percentage of waste foundry sand in the mix such as 10 and 20%, the percentage decrease in the mix was 7.14% and 14.28%, respectively; however, further increase in the mix did not show any changes in the plastic limit. Thus, the optimum percentage of waste foundry sand in the mix was 20% (Kumar et al. 2011). The inclusion of coarser particles in the soil may be the cause of the

decrease in the plastic limit with an increase in the proportion of waste foundry sand. Moreover, the addition of waste foundry sand to clayey soil decreases the liquid limit due to the non-plastic nature of waste foundry sand, hence reducing the swelling of the soil and minimizing the probability of foundation cracks (Bhardwaj and Sharma 2020; Heidemann et al. 2021).

Figure 5 shows variation of plasticity index in the mix with the addition of waste foundry sand. With the increase in the percentage of waste foundry sand in the mix, i.e., 10, 20, and 30%, the percentage decrease in the plasticity index was 2.5%; however the further increase in the percentage of waste foundry sand up to 40% resulted in decrease of plasticity index. Hence, the optimum percentage of waste foundry sand in the mix was 20% (Kumar et al. 2011). The increase in the percentage of the waste foundry sand in the mix, i.e., 10, 20, 30, and 40%, resulted in the decrease in the percentage decrease of plasticity index such as 22.58%, 35.48%, 38.70%, and 51.61% respectively (Heidemann et al. 2021). With the increase in the percentage of waste foundry sand up to 20%, there was a decrease in the percentage of plasticity index from 5.71 to 11.42%. However, further decrease in the percentage of waste foundry sand did not show any change in the plasticity index. Thus, the optimum percentage of waste foundry sand was 20% (Bhardwaj and Sharma 2020). The decrease in the plasticity index as the amount of waste foundry sand increases may be owing to the addition of coarser particles to the soil, which are cohesion less in nature. Moreover, the decrease in the plasticity index of soil may also be due to the decrease in

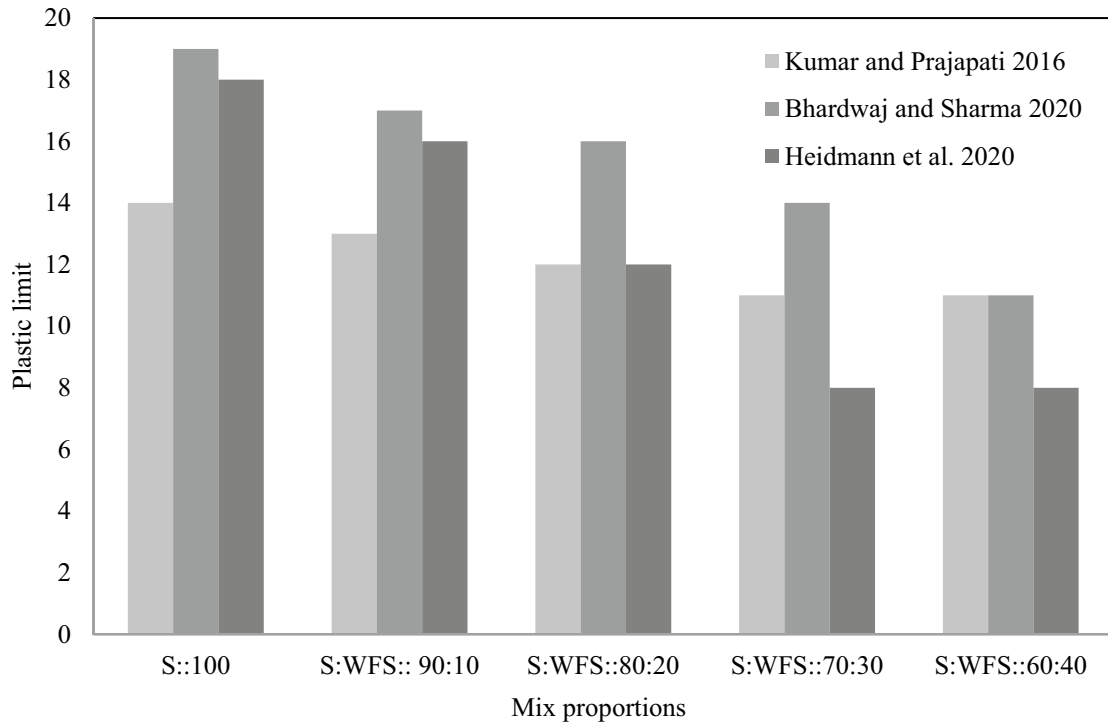


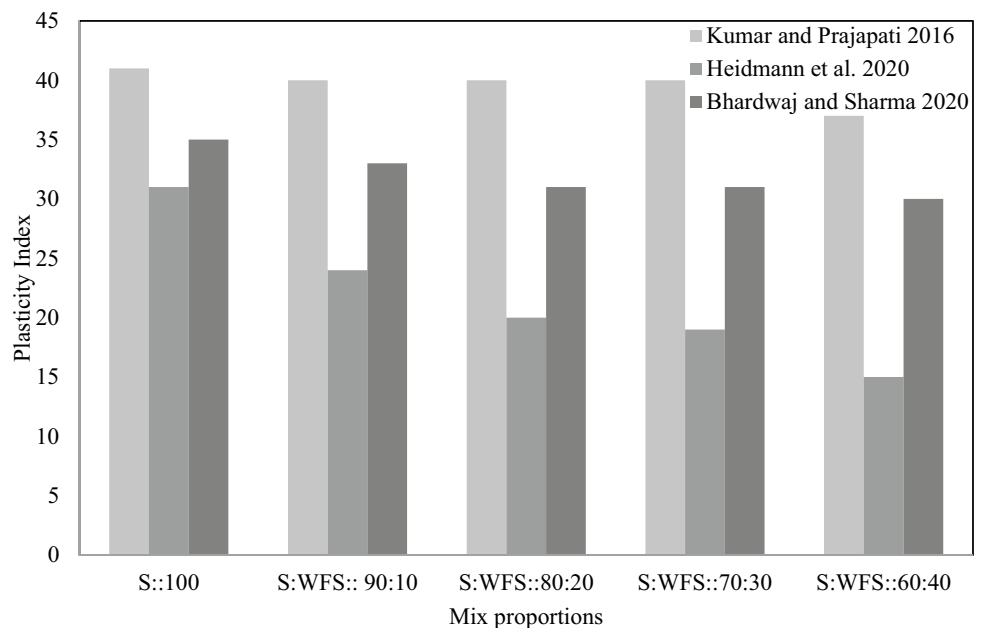
Fig. 5 Variation of plastic limit with the addition of waste foundry sand in the mix

the thickness of the double diffused layer. The reduction in thickness is due to the addition of percentage of waste foundry sand in the mix (Bhardwaj and Sharma 2020; Heidemann et al. 2021) (Fig. 6).

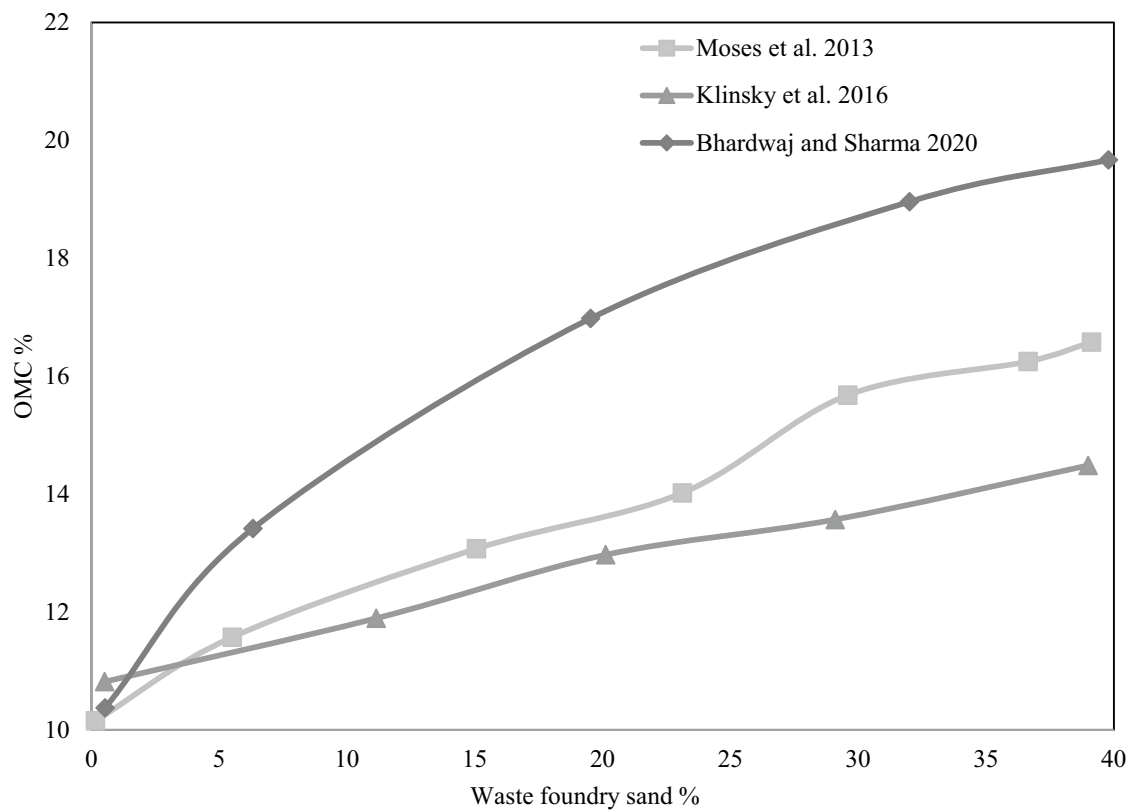
**Compaction tests**

Compaction is the process of densification of soil by minimizing air voids with the help of mechanical methods. The degree of compaction of a soil is measured in terms of its dry unit weight. Figure 7 shows variation of optimum moisture content (OMC) of soil–WFS mixes. There was an increase

Fig. 6 Variation of plasticity index with the addition of waste foundry sand in the mix







**Fig. 7** Variation of OMC with foundry sand

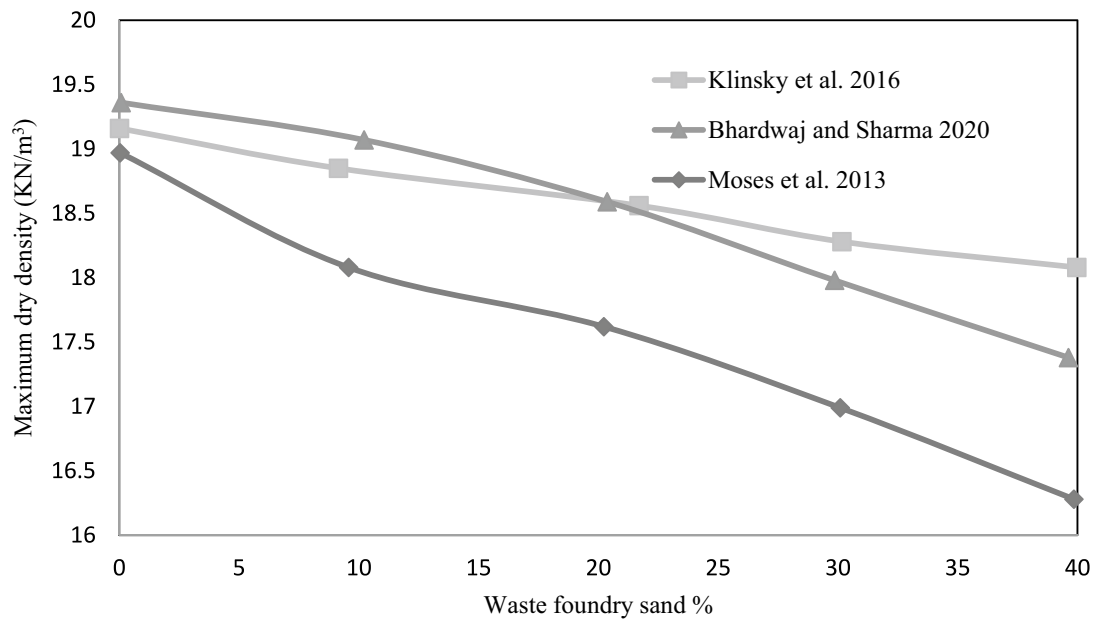
in OMC from 10 to 16% with the increase in the percentage of waste foundry sand in the mix, i.e., 10 to 40% (Moses et al. 2013). The OMC values increased from 11 to 15% with the increase in WFS from 0 to 40% (Klinsky et al. 2016). The OMC values increased to 20% with the increase in the percentage of waste foundry sand from 0 to 40% (Bhardwaj and Sharma 2020). The addition of waste foundry sand containing bentonite (rich in the montmorillonite mineral) increases the water holding capacity of WFS, which may be the cause of the increase in OMC value of the C: WFS mixture. In addition to this due to the presence of sand particles with a higher specific area than virgin soil, the OMC value may increase after the addition of WFS (Kumar et al. 2016; Moses et al. 2013; Sharma and Hymavathi 2016).

Figure 8 shows the variation of maximum dry density (MDD) with the soil–WFS mixes. The MDD values decreased from 18.97 to 16.28 KN/m<sup>3</sup> with the increase in the percentage of waste foundry sand from 0 to 40% (Moses et al. 2013). The value of MDD decreased from 19.16 up to 18.08 KN/m<sup>3</sup> when the soil was replaced by 40% of waste foundry sand (Klinsky et al. 2016). The increase in the percentage of waste foundry sand in the mix (i.e., up to 40%) resulted in the decrease of MDD values from 19.36 KN/m<sup>3</sup> up to 17.38 KN/m<sup>3</sup> (Bhardwaj and Sharma 2020). The increase in MDD value of clayey soil is due to the greater

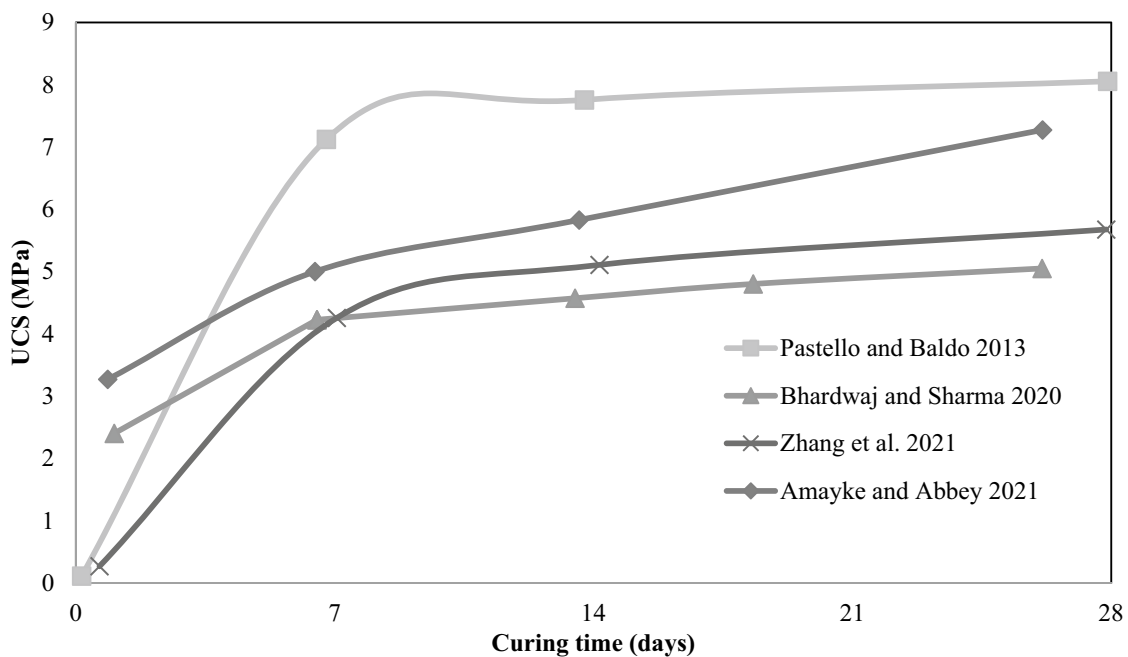
surface area of WFS particles as compared to clayey soil particles. Furthermore, the higher specific gravity of WFS particles as compared to clay may result in an increase in the MDD value of C: WFS mixtures (Klinsky et al. 2016; Moses et al. 2013; Sharma and Hymavathi 2016).

### Unconfined compressive strength test

The unconfined compressive strength is a common measure to determine strength of roadways and is frequently used to establish the structural layers for designing pavement layers. Figure 9 shows the variation of UCS with curing time (in days) by different authors. Strength testing follow the procedures outlined in ASTM D–1633. The unconfined compressive strength values elevated from 0 up to 8.05 MPa with the increase in the percentage of WFS from 0 to 40% (Pasetto and Baldo 2015). To find the effect of waste foundry sand on the strength characteristics, the UCS tests were conducted on clayey soil in accordance with ASTM–D 2166–16. On adding 0–20% WFS to clayey soil, the UCS of mixture after 28 days of curing increased from 1 to 5 MPa after curing the sample for 28 days (Bhardwaj and Sharma 2020). The UCS increased from 0.6 to 5.6 MPa with the increase in the percentage of WFS in the mix from 0 to 40% after curing the sample for 28 days (Zhang et al. 2021). The unconfined



**Fig. 8** Variation of MDD with waste foundry sand



**Fig. 9** Variation of UCS with curing time (in days) by different authors

compressive strength tests were conducted to determine the stress–strain characteristics and strength of the subgrade in accordance with the relevant standards. With the addition of waste foundry sand in the soil from 0 to 40%, the compressive strength increased from 3.86 to 7.27 MPa after curing the sample for 28 days (Amayke and Abbey 2021). The increase in the unconfined compressive strength is usually due to progression of smaller particles into larger ones

which leads to several chemical reactions viz. pozzolanic activities, cation exchange etc. These large-sized particles are more resistant to compressive loads than untreated small-sized particles of clayey soil. Furthermore, the increase in UCS value resulting from the addition of WFS may be due to the compact structure and densification caused by the WFS. Further investigation into the effect of curing period of various combinations indicated that the UCS values of all

composites increased as the curing period increased from 1 to 7 and then to 28 days (Bhardwaj and Sharma 2020; Klinsky et al. 2016).

### California bearing ratio

California bearing ratio is used to determine the strength of stabilized subgrade material to obtain the bearing capacity of subgrade. CBR tests were conducted in accordance with ASTM D1883 in various samples compacted under optimum moisture content and maximum dry density (Pooni et al. 2022). Figure 10 depicts the California bearing ratio values of soil with varied percentages of foundry sand. The CBR values increased from 8.65 to 11.65% when foundry sand was increased to 10%; it increased to 13.26 when the percentage of foundry sand was increased to 14%. Similarly, CBR was increased to 15.87 on addition of 18% foundry sand and a significant increase in CBR of 18.65% was achieved at 22% waste foundry sand. Hence, the optimum percentage of waste foundry sand considered for subgrade was 22% (Klinsky et al. 2016). Foundry sand was mixed in proportions ranging from 0 to 10% by weight of the soil increased CBR value from 1.6 to 11%. The increase in CBR reflected in reduction in the overall thickness of subgrade. Therefore, 10% of WFS was taken as optimum content in the soil mix (Amakye and Abbey 2021). Results from an investigation where waste foundry sand was replaced by 0 to 20% in expansive soil showed higher CBR values such as 6–16% hence suitable for roads, subgrade and embankments. The highest CBR value, i.e., 16%, was achieved in expansive subgrade in the pavement construction when 20% of waste foundry sand was used as an additive (Yadav and Kumar 2019). Clayey soil mixed with foundry sand with ratio from 0 to 20% achieved an increase in CBR value from

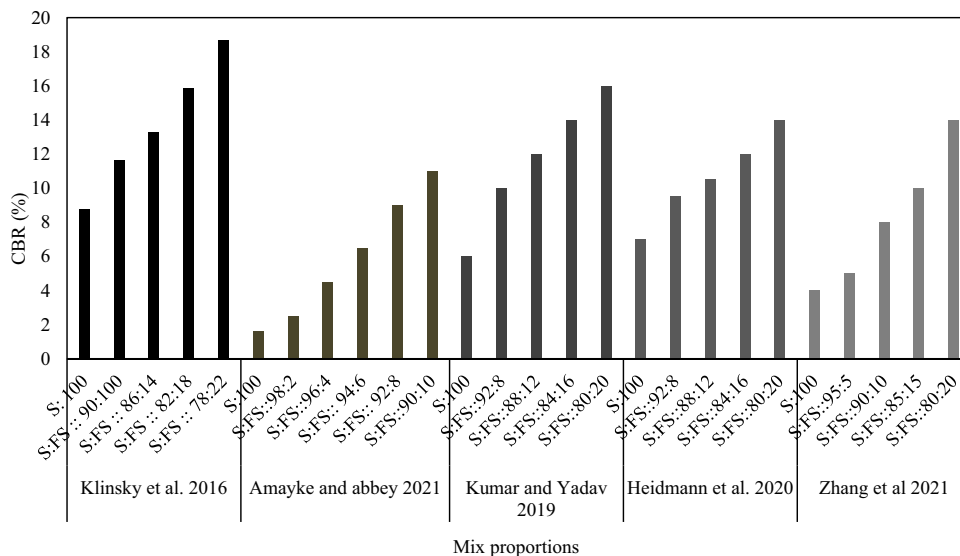
7 to 14%. Hence, 20% of waste foundry sand was considered the optimum percentage of additive in the mix (Heidemann et al. 2021). CBR values increased with varying contents of waste foundry sand at 0%, 5%, 10%, 15%, and 20%. The CBR values obtained were 4, 5, 8, 10, and 14%, respectively. Therefore, 20% of waste foundry sand was considered the optimum percentage of additive in the mix (Zhang et al. 2021). The improvement in CBR values may be due to the compact structure and densification caused by the addition of waste foundry sand in the mix. This densification is due to condense packing and intermolecular attraction which further leads to increase in the density of the mix. In other words, the addition of WFS increases the CBR value which occurs due to interlocking of the coarser particles and variation in the cohesive nature of the soil–WFS composite. Furthermore, the presence of sand particles in the WFS also contributes to the increase in CBR by mobilizing the angle of internal friction, which increases strength (Amakye and Abbey 2021; Klinsky et al. 2016; Pooni et al. 2022).

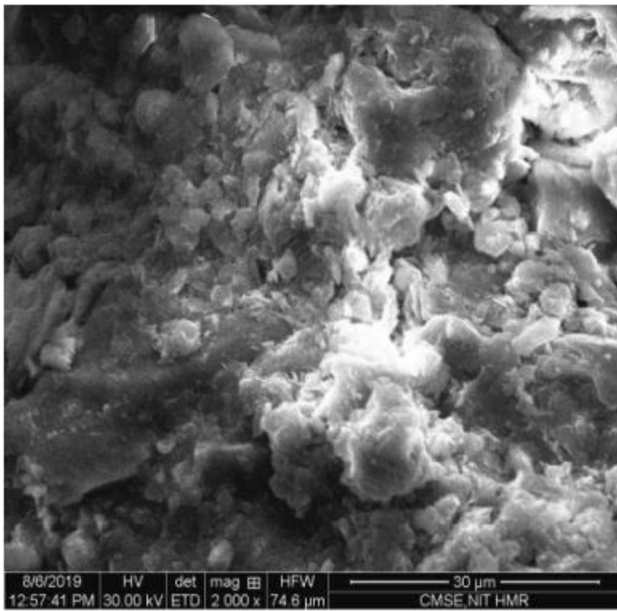
### Microstructure

The scanning electron microscope analysis is used to examine the change in the structure of soil when additives are added to it. The SEM image of soil depicts the existence of plate like structures containing number of voids in it. With the inclusion of optimum percentage of waste foundry sand in the mix (i.e., 20%), there was an increase in the strength of the mix hence giving it a compact structure (Bhardwaj and Sharma 2020). Figure 11 shows the images of scanning electron microscope analysis when clay was mixed with foundry sand.

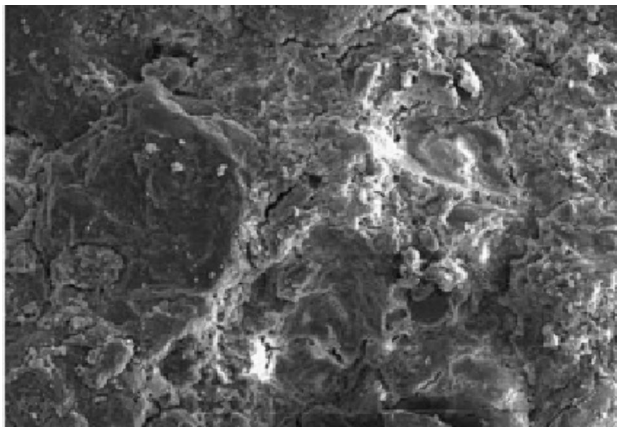
Figure 12 shows images of SEM analysis when foundry sand was added to soil. The same image also indicates that

Fig. 10 CBR values given by various researchers





**Fig. 11** Scanning electron microscopy analysis of clay with waste foundry sand (Bhardwaj and Sharma 2020)



**Fig. 12** SEM analysis of clay with waste foundry sand and lime (Guney et al. 2006)

the majority of the silica in the foundry sand was converted into calcium silicate hydrates, which stiffened the specimen. In addition, the presence of oxygen (i.e., air) in the apertures of the foundry sand dropped, probably as a result of a reduction in hydraulic conductivity (Guney et al. 2006).

## Conclusions

Various chemical agents like cement and lime have been used for stabilization of subgrade soil. However, the chemicals used can be harmful to environment as well as can be overpriced. Thereupon use of non-traditional stabilizers such

as foundry sand is adopted which results in improvement of the engineering properties of subgrade soil and proves eco-friendly and economical. Following conclusions can be drawn from this paper:

- Foundry sand is a waste material which is granular or subgranular having lesser unit weight and the voids in case of foundry sand are usually more than that of conventional sand.
- Atterberg's limits such as liquid limit and plastic limit values decrease with the increase in the percentage of waste foundry sand in the mix. This decrease in the percentages of liquid and plastic limit is mainly due to inclusion of coarser particles in the composite. The addition of coarser particles decreases the surface charge which results in the reduction in the amount of absorbed water, thus leads to decrease in the Atterberg's limits.
- With the increase in the percentage of foundry sand in the mix both optimum moisture content and maximum dry density increases. The reduction in optimum moisture content and maximum dry density value on adding waste foundry sand to clayey soil may be because of the transition of finer particles to coarser particles resulting in lesser void ratio.
- Furthermore, California bearing ratio values increases with the increase in the percentage of waste foundry sand. It occurs due to interlocking of the coarser particles and variation in the cohesive nature of the soil–WFS composite. This increase in the percentage of CBR values results in the improvement of the strength of the mix, therefore, it can be utilized as a subgrade material.
- The addition of waste foundry sand in the mix increases the unconfined compressive strength after a curing period of 28 days. The increase in the unconfined compressive strength is usually due to progression of smaller particles into larger ones which leads to several chemical reactions viz. pozzolanic activities, cation exchange etc. The small sized particles have less resistance towards compression in comparison with the large sized particles. Hence, the increase in the unconfined compressive strength value on addition of waste foundry sand may be due to firm composition induced by waste foundry sand.

Waste foundry sand is an apt material that can be used in the subgrade soil to improve the geotechnical properties and minimize the pollution by utilizing the waste material.

## Future scope

The inclusion of additives to expansive soils on site is only capable of stabilizing the soil to a shallow depth, making it unsuitable for extensive soil stabilization. The simple

availability and low cost of waste materials employed in subgrade stabilization hold the key to a sustainable future. The use of WFS in such a variety of applications as a substitute for conventional materials can aid in several ways in conserving conventional materials, decreasing cost and reducing environmental load, thereby benefiting the environment. The beneficial use of WFS encompasses variety of applications such as highway embankment construction, ground improvement etc. However limited research has been done on impact of waste foundry sand on properties such as permeability, freezing and thawing, DFS, long-term curing, and split tensile strength. Hence, there is a need of more research on effects of WFS on all these soil properties.

## References

- Abichou T, Benson CH, Edil TB (2000) Foundry green sands as hydraulic barriers: laboratory study. *J Geotechn Geoenviron Eng* 126(12):1174–1183
- Ahmad J, Aslam F, Zaid O, Alyousef R, Alabduljabbar H (2021) Mechanical and durability characteristics of sustainable concrete modified with partial substitution of waste foundry sand. *Struct Concr* 22:2775–2790
- Ahmad J, Zhou Z, Martínez-García R, Vatin NI, de Prado-Gil J, El-Shorbagy MA (2022) Waste foundry sand in concrete production instead of natural river sand: a review. *Materials* 15(7):2365
- Altaf S, Singh K, Sharma A (2023) Sustainable utilization of waste foundry sand and sodium chloride in soil stabilization. *J Min Environ* 14(3):897–908
- Amakye SY, Abbey SJ (2021) Understanding the performance of expansive subgrade materials treated with non-traditional stabilizers: a review. *Clean Eng Technol* 4:100159
- Anand D, Sharma RK, Sharma A (2021) Improving swelling and strength behavior of black cotton soil using lime and quarry dust. In *Sustainable development through engineering innovations* (pp. 601–609). Springer, Singapore.
- Aneke FI, Awuzie B (2018) Conversion of industrial wastes into marginal construction materials. *Acta Structilia* 25(2):119–137
- Aneke FI, Shabangu C (2021) Green-efficient masonry bricks produced from scrap plastic waste and foundry sand. *Case Stud Constr Mater* 14:e00515
- Anupam AK, Kumar P, Ransinchung GD (2013) Use of various agricultural and industrial waste materials in road construction. *Procedia Soc Behav Sci* 104:264–273
- Başar HM, Aksoy ND (2012) Recovery applications of waste foundry sand. *J Eng Nat Sci* 30:205–224
- Bhardwaj A, Sharma RK (2020) Effect of industrial wastes and lime on strength characteristics of clayey soil. *J Eng Des Technol* 18(6):1749–1772
- Bhardwaj A, Sharma RK, Sharma A (2021) Stabilization of clayey soil using waste foundry sand and molasses. In *Sustainable development through engineering innovations* (pp. 641–649). Springer, Singapore.
- Bilal H, Yaqub M, Rehman SKU, Abid M, Alyousef R, Alabduljabbar H, Aslam F (2019) Performance of foundry sand concrete under ambient and elevated temperatures. *Materials* 12:2645
- Bozbey I, Garaisayev S (2010) Effects of soil pulverization quality on lime stabilization of an expansive clay. *Environ Earth Sci* 60(6):1137–1151
- Dayton EA, Whitacre SD, Dungan RS, Basta NT (2010) Characterization of physical and chemical properties of spent foundry sands pertinent to beneficial use in manufactured soils. *Plant Soil* 329(1):27–33
- Deng A, Tikalsky PJ (2008) Geotechnical and leaching properties of flowable fill incorporating waste foundry sand. *Waste Manage* 28(11):2161–2170
- Dogan-Saglamtimur N (2018) Waste foundry sand usage for building material production: a first geopolymer record in material reuse. *Adv Civ Eng* 2018:1927135
- Dungan RS, Kukier U, Lee B (2006) Blending foundry sands with soil: effect on dehydrogenase activity. *Sci Total Environ* 357(1–3):221–230
- Eko RM, Riskowski G (2001) A procedure for processing mixtures of soil, cement, and sugar cane bagasse
- Fox PJ, Mast DG (1998) Geotechnical performance of highway embankment constructed using waste foundry sand. FHWA/IN/JTRP-98/18. Joint Transportation Research Program. Indiana Department of Transportation and Purdue University. West Lafayette, Indiana, United States
- Gazi A (2018) Utilization of waste foundry sand as highway material (Master's thesis, Fen Bilimleri Enstitüsü)
- Goodhue MJ, Edil TB, Benson CH (2001) Interaction of foundry sands with geosynthetic journal of geotechnical and geoenvironmental engineering. *ASCE* 127:353–362
- Guney Y, Aydilek AH, Demirkan MM (2006) Geoenvironmental behavior of foundry sand amended mixtures for highway sub bases. *Waste Manage* 26(9):932–945
- Guney Y, Sari YD, Yalcin M, Tuncan A, Donmez S (2010) Re-usage of waste foundry sand in high-strength concrete. *Waste Manag* 30:1705–1713
- Harichane K, Ghrici M, Kenai S, Grine K (2011) Use of natural pozzolana and lime for stabilization of cohesive soils. *Geotech Geol Eng* 29:759–769
- Heidemann M, Nierwinski HP, Hastenpflug D, Barra BS, Perez YG (2021) Geotechnical behavior of compacted waste foundry sand. *Constr Build Mater* 277:122267
- Ikeagwuani CC, Nwonu DC (2019) Emerging trends in expansive soil stabilization: a review. *J Rock Mech Geotech Eng* 11(2):423–440
- Iqbal MF, Liu QF, Azim I (2019) Experimental study on the utilization of waste foundry sand as embankment and structural fill. In *IOP conference series: materials science and engineering* (Vol. 474, No. 1, p. 012042). IOP Publishing.
- Javed S, Lovell CW (1994) (1994) Uses of waste foundry sands in civil engineering. *Transp Res Rec* 1486:109–113
- Johnson CK (1981) Phenols in foundry waste sand
- Kaur G, Siddique R, Rajor A (2012) Properties of concrete containing fungal treated waste foundry sand. *Constr Build Mater* 29:82–87
- Kleven JR, Edil TB, Benson CH (2000) Evaluation of excess foundry system sands for use as sub-base material. *Transp Res Board* 1714:40–48
- Klinsky LMG, Fabbri GTP, Santos Bardini VSD (2016) Reuse of waste foundry sand mixed with lateritic clayey soils in pavement bases and sub-bases courses. 8th RILEM International Symposium on Testing and Characterization of Sustainable and Innovative Bituminous Materials. Springer, Dordrecht, pp 569–582
- Kolias S, Kasselouri-Rigopoulou V, Karahalios A (2005) Stabilization of clayey soils with high calcium fly ash and cement. *Cement Concr Compos* 27(2):301–313
- Kumar S, Prajapati DR, Satsangi PS (2011) Design for Six Sigma to optimise the process parameters of a foundry. *Int J Prod Qual Manag* 8(3):333–355
- Kumar A, Kumari S, Sharma RK (2016) Influence of use of additives on engineering properties of clayey soil. *Proceedings of National conference: Civil Engineering Conference-Innovation for Sustainability (CEC-2016)*.

- Manoharan T, Laksmanan D, Mylsamy K, Sivakumar P, Sircar A (2018) Engineering properties of concrete with partial utilization of used foundry sand. *Waste Manage* 71:454–460
- McIntyre SW, Rudman KB, Baillo CR, Sandell PR, Stillwell B (1992) Beneficiation and reuse of foundry sand residuals: a preliminary report transactions of the American Foundry men's Society. 100:201–208
- Miguel RE, Ippolito JA, Leytem AB, Porta AA, Noriega RBB, Dungan RS (2012) Analysis of total metals in waste molding and core sands from ferrous and non-ferrous foundries. *J Environ Manage* 110:77–81
- Mishra B (2014) A Study on characteristics of subgrade soil by use of foundry sand and Iron turnings. *Int J Sci Res (IJSR)*, ISSN (Online) 2319–7064
- Moses G, Afolayan JO (2011) Compacted foundry sand treated with cement kiln dust as hydraulic barrier material. *Electron J Geotech Eng* 16:337–355
- Moses G, Oriola FOP, Afolayan JO (2013) The impact of compactive effort on the long-term hydraulic conductivity of compacted foundry sand treated with bagasse ash and permeated with municipal solid waste landfill leachate. *Front Geotech Eng* 2(1):7
- Naik TR, Patel VM, Parikh DM, Tharaniyil MP (1994) Utilization of used foundry sand, Department of Civil Engineering & Mechanics. University of Wisconsin – Milwaukee. United States.
- Noronha Marques E, Bergmann CP, Masuero AB (2023) Analysis of the technical feasibility of sustainable concrete production using waste foundry sand as a fine aggregate. *ACS Omega* 8(49):46406–46413
- Nuryati S, Nurrahman I, Yulius E, Paryati N, Gunarti ASS, Darma E (2023) The utilization of marble and cement powder as material for highway subgrade soil stabilization. In *AIP Conference Proceedings* (Vol. 2706, No. 1). AIP Publishing.
- Osinubi KJ, Moses G, Liman AS (2015) The influence of compactive effort on compacted lateritic soil treated with cement kiln dust as hydraulic barrier material. *Geotech Geol Eng* 33:523–535
- Partridge BK, Alleman JE (1998) Field demonstration of highway embankment constructed using waste foundry sand. FHWA/IN/JTRP-98/8. Joint Transportation Research Program. Indiana Department of Transportation and Purdue University. West Lafayette. Indiana. United States
- Pasetto M, Baldo N (2015) Experimental analysis of hydraulically bound mixtures made with waste foundry sand and steel slag. *Mater Struct* 48(8):2489–2503
- Pooni J, Robert D, Giustozzi F, Gunasekara C, Setunge S, Venkatesan S (2022) Hydraulic characteristics of stabilised expansive subgrade soils in road pavements. *Int J Pavement Eng* 23(9):3129–3146
- Prabhu GG, Hyun JH, Kim YY (2014) Effects of foundry sand as a fine aggregate in concrete production. *Constr Build Mater* 70:514–521
- Prasad VD, Prakash EL, Abishek M, Dev KU, Kiran CKS (2018) Study on concrete containing waste foundry sand, fly ash and polypropylene fibre using Taguchi method. *Mater Today Proc* 5:23964–23973
- Reshma TV, Manjunatha M, Sankalpasri S, Tanu HM (2021) Effect of waste foundry sand and fly ash on mechanical and fresh properties of concrete. *Mater Today: Proc* 47:3625–3632
- Sharma RK, Hymavathi J (2016) Effect of fly ash, construction demolition waste and lime on geotechnical characteristics of a clayey soil: a comparative study. *Environ Earth Sci* 75(5):1–11
- Sharma A, Sharma RK (2019) Effect of addition of construction–demolition waste on strength characteristics of high plastic clays. *Innov Infrastruct Solutions* 4(1):1–11
- Sharma A, Sharma RK (2020) Strength and drainage characteristics of poor soils stabilized with construction demolition waste. *Geotech Geol Eng* 38(5):4753–4760
- Sharma A, Sharma RK (2021a) An experimental study on uplift behaviour of granular anchor pile in stabilized expansive soil. *Int J Geotech Eng* 15(8):950–963
- Sharma A, Sharma RK (2021b) Sub-grade characteristics of soil stabilized with agricultural waste, constructional waste, and lime. *Bull Eng Geol Env* 80(3):2473–2484
- Siddique R, Singh G (2011) Utilization of waste foundry sand (WFS) in concrete manufacturing. *Resour Conserv Recycl* 55(11):885892
- Siddique R, Kaur G, Rajor A (2010) Waste foundry sand and its leachate characteristics. *Resour Conserv Recycl* 54(12):1027–1036
- Siddique R (2007) Waste materials and by-products in concrete. Springer Science & Business Media
- Smarzewski P (2020) Mechanical properties of ultra-high-performance concrete with partial utilization of waste foundry sand. *Buildings* 10(1):11
- Sujjavanidi S, Duangchan A (2004) Pozzolanic reactivity and water requirement of bagasse ash. In *Proc. In the 2nd Concrete National Conference* (pp. 27–28)
- Taye B, Araya AA (2015) Stabilization of expansive clay soil with sugar cane molasses and cement. *Proceedings of the 2nd International Conference on Transportation in Africa (ICTA2015)* Majestic Five Hotel, Palapye, Botswana
- Thiruvengadam M, Pandian S, Santra M, Subramanian D (2020) Use of waste foundry sand as a partial replacement to produce green concrete: mechanical properties, durability attributes and its economical assessment. *Environ Technol Innov* 19:101022
- Tittarelli F (2018) Waste foundry sand. In *Waste and Supplementary Cementitious Materials in Concrete* (pp. 121–147). Woodhead Publishing
- Winkler ES, Bolshakov AA (2000) Characterization of foundry sand waste. Chelsea Center for Recycling and Economic Development University of Massachusetts at Lowell. United States
- Yadav AP, Kumar EN (2019) A comparative study of waste foundry sand and marble dust for stabilization of subgrade soil. *Int J Res Appl Sci Eng Technol*
- Yazoghli-Marzouk O, Vulcano-Greullet N, Cantegrit L, Friteyre L, Julien A (2014) Recycling foundry sand in road construction–field assessment. *Constr Build Mater* 61:69–78
- Zhang Y, Sappinen T, Korkiala-Tanttu L, Vilenius M, Juuti E (2021) Investigations into stabilized waste foundry sand for applications in pavement structures. *Resour Conserv Recycl* 170:105585