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Laboratory assessment of the influence of the proportion of waste foundry sand on the geotechnical engineering properties of clayey soils

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Soil improvement can be achieved through mechanical stabilisation using industrial by-products. Clayey soils were blended with waste foundry sand to examine its influence on the geotechnical engineering properties of the soils. The waste foundry sand was first subjected to standard geotechnical engineering testing. The effect of the foundry waste sand on the modification of the plasticity, swell potential, compaction characteristics and CBR values of the soils is demonstrated in this paper. The results show that the addition of waste foundry sand improves the performance potential of otherwise marginal materials for use in geotechnical engineering applications.

INTRODUCTION

Soils that lack certain attributes for suitability as construction materials are either chemically treated or blended with other materials to make them acceptable for geotechnical engineering applications. Hydrated lime and Portland cement have been the traditional additives used for soil improvement.

Industrial by-products are slowly finding applications in soil improvement. For example, Nikraz (1999) studied the effectiveness of lime kiln dust (LKD) as a soil stabiliser. Zaman *et al* (1992) investigated the use of cement kiln dust (CKD), a cement by-product, produced during the production of Portland cement, as a soil stabiliser for a highly expansive soils, while Collins and Ciesielske (1994) presented a review of the uses of various types of slags. Chun and Kao (1993) presented a study on the stabilisation of a clayey soil, using fly ash and slag. Edil *et al* (2002) evaluated a variety of industrial by-products for soil stabilisation, including fly ash.

Most recently, the use of foundry waste sand in soil improvement has also been investigated. Several uses of foundry waste sands have been cited in the literature. In Kleven *et al* (2000) and Edil *et al* (2002), their investigations included foundry waste sand, which demonstrated the capacity to provide adequate support as a sub base. The Foundry Industry Recycling Starts Today (FIRST) website [www.founddryrecycling.org] provides information on foundry waste sand and list of projects where foundry waste sand has been used. FIRST has authored a report (Foundry Sand Facts for Civil Engineers, FIRST (2004)) which provides technical information about the potential civil engineering applications of foundry sand including construction practice. Javed and Lovell (1995) describe a number of uses of foundry waste sand in geotechnical engineering application, which include flowable-fills and asphalt concrete.

A review of the literature, revealed that there was no technical information in the public domain on the assessment of the utilisation of foundry waste sand for geotechnical engineering applications in South Africa. The assumption that industrial by-products are most likely to be influenced by the inputs and processes involved in their

Table 1 Properties of the weathered shale, sample PEWS

Characteristics	Value/ classification
Liquid limit	40,0
Plasticity index of whole sample	22,3
Linear shrinkage	9,50
Percentage <0,002	29,70
Grading modulus	0,23
PRA classification	A-7-5
Unified soil classification	CI
Activity	0,7
Heave classification	Medium

Table 2 Properties of the foundry waste sand used in the study

Characteristics	Value/ classification
Liquid limit	26,5
Plasticity index of whole sample	7
Linear shrinkage	0,00
Percentage <0,002	4,0
Grading modulus	0,96
PRA classification	A-2-4
Unified soil classification	SC
Activity	1,6
Heave classification	LOW

Abbreviations:

HGSB – Sample from Hogsback area
PEWS – Port Elizabeth weathered shale sample
UT1 – Sample 1 from Uitenhage
UT2 – Sample 2 from Uitenhage
SDW – Sample from Sidwell area
WF sand – Waste foundry sand

Keywords: waste foundry sand, beneficial use, materials, geotechnical properties, clayey soils

Table 3 Influence of adding waste sand on the grading characteristics and classification

Proportion of waste sand by weight (%)	Percentage passing 0,002 mm sieve	Grading modulus	PRA classification	Unified soil classification	Activity	Heave classification
0	29,70	0,23	A-7-5	CI	0,7	Med
20	18,00	0,40	A-6	CL	1,0	Med
30	15,84	0,48	A-6	CL	1,0	Med
40	15,84	0,53	A-6	SC	1,0	Med
50	12,87	0,61	A-6	SC	1,0	Med
60	12,38	0,70	A-2-6	SC	1,0	Low
70	6,79	0,79	A-2-4	SC	1,0	Low
80	6,79	0,80	A-2-4	SC/SM	1,0	Low
100 (pure waste sand)	4,00	0,96	A-2-4	SC	1,6	Low

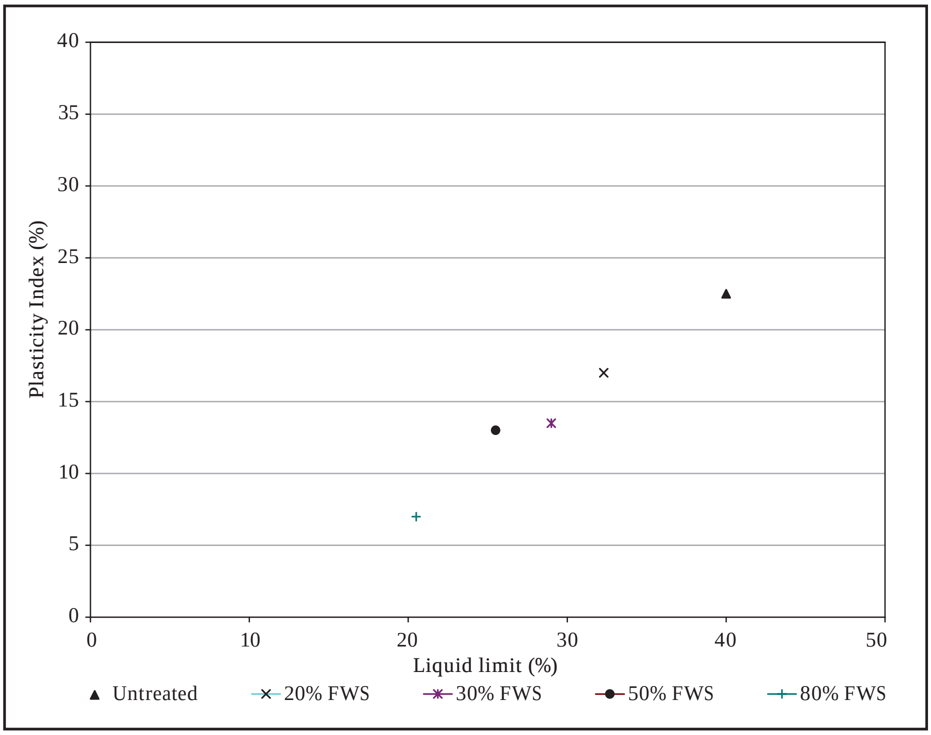

Figure 1 Influence of the addition of foundry waste sand on the variation of liquid limit and plasticity index

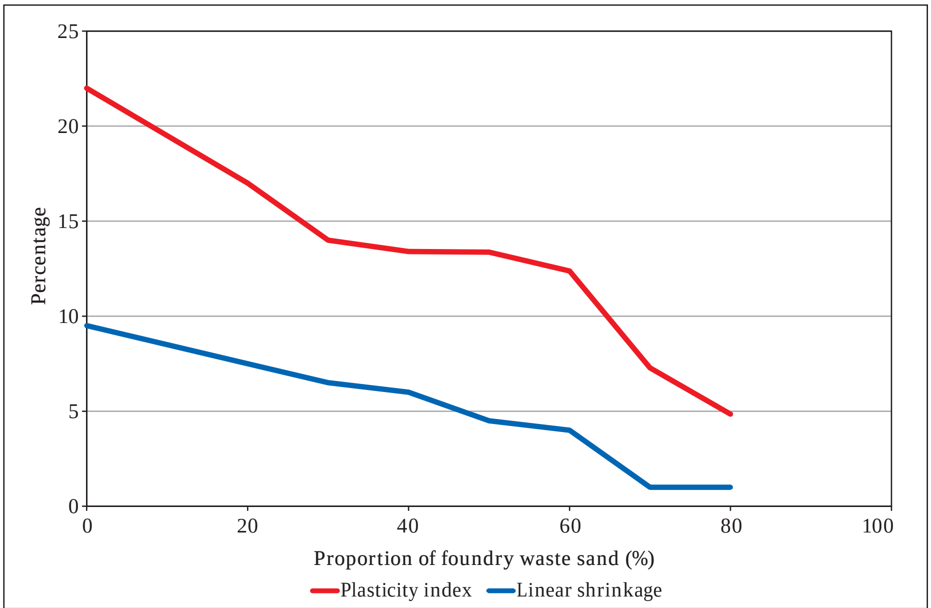

Figure 2 Rate of variation of liquid limit and plasticity index

production, making them source dependent, justifies the need to establish local knowledge in the use of foundry waste sand for geotechnical engineering applications.

Edil and Benson (2002) have stated six specific issues related to the development of industrial by-products as geo-materials, which should act as a guide in such an evaluation. These steps are the identification and property evaluation; environmental assessment; prediction, field verification and long-term performance; constructability and field verification of performance; construction specifications and finally dissemination and availability of technical information. Such a process has not yet been done on waste foundry sand in South Africa.

In view of the abovementioned specific issues, the objective of the study being reported in this paper was to address the first specific issue, namely to identify the geotechnical engineering properties of a foundry waste sand from a foundry in Port Elizabeth, South Africa, and assess its potential in geotechnical engineering applications. On the basis of the initial study, performing an extensive and detailed study could then be justified. The paper therefore describes the initial laboratory tests of a planned extensive testing programme to assess the effectiveness of this foundry waste sand, as an alternative soil stabiliser. The tests were performed at the Department of Civil Engineering laboratory of Nelson Mandela Metropolitan University.

EXPERIMENTAL STUDY

Five clayey soil samples from different locations in and around the city of Port Elizabeth, including one sample from Hogsback, some 350 km away, were used in this study. However, the first series of tests concentrated on a weathered shale sample collected from a location near the Corobrik site. The tests were conducted on the original control sample and on mixtures having different proportions of the waste foundry sand. The test series were carried out according to TMH1. After determining the resulting changes on the plasticity, compaction characteristics, CBR and swell potential on the weathered shale, selected tests were conducted on the other four samples.

Soil properties

The geotechnical engineering properties of the weathered shale are shown in table 1.

Foundry waste sand

Foundry waste sand is a by-product of the ferrous and nonferrous metal casting industry. It is the excess sand that is discarded after re-use in metal casting as moulding material. The foundry waste sand used in this study was collected from a foundry in Port Elizabeth. It has a black colour, due to the addition of about 1,5 % coal dust during the industrial processes to prevent the sand from sticking to the casting. The particle size distribution analysis revealed that 97 % passed through the 600 µm sieve and about 16 % passed through the 75 µm sieve. A

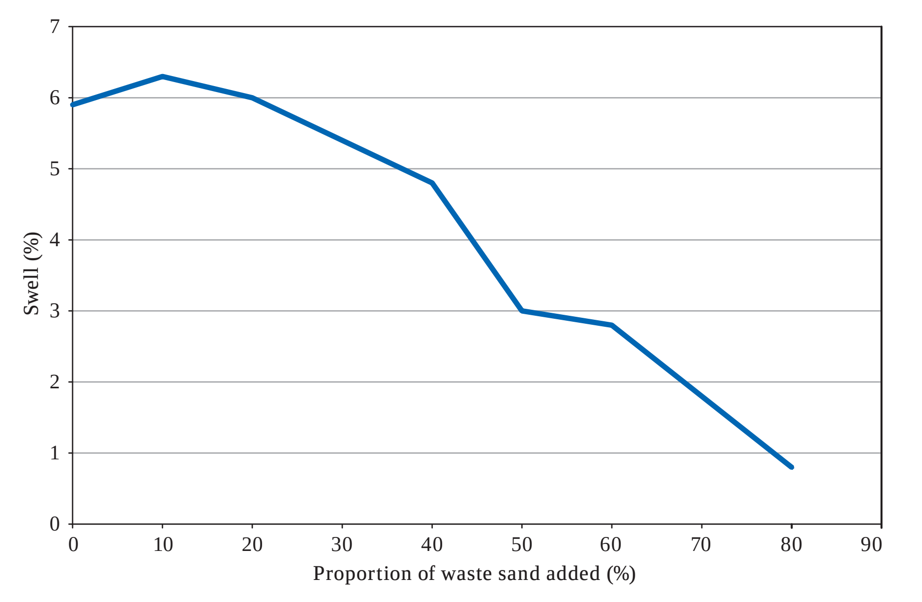

Figure 3 Influence of foundry waste sand content on swelling of weathered shale

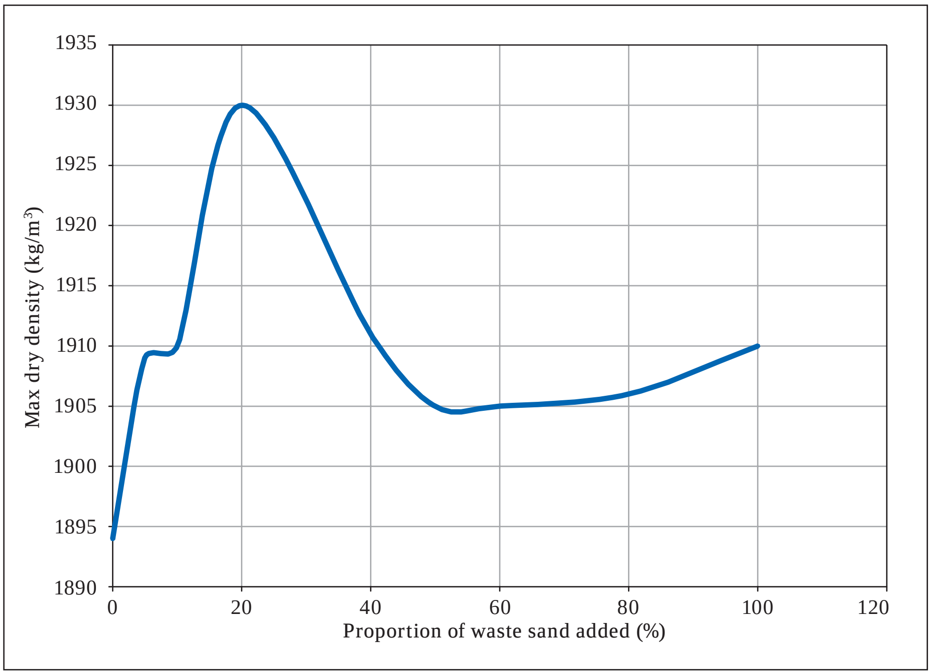

Figure 4 Effect of the proportion of foundry waste sand on maximum dry density of weathered shale

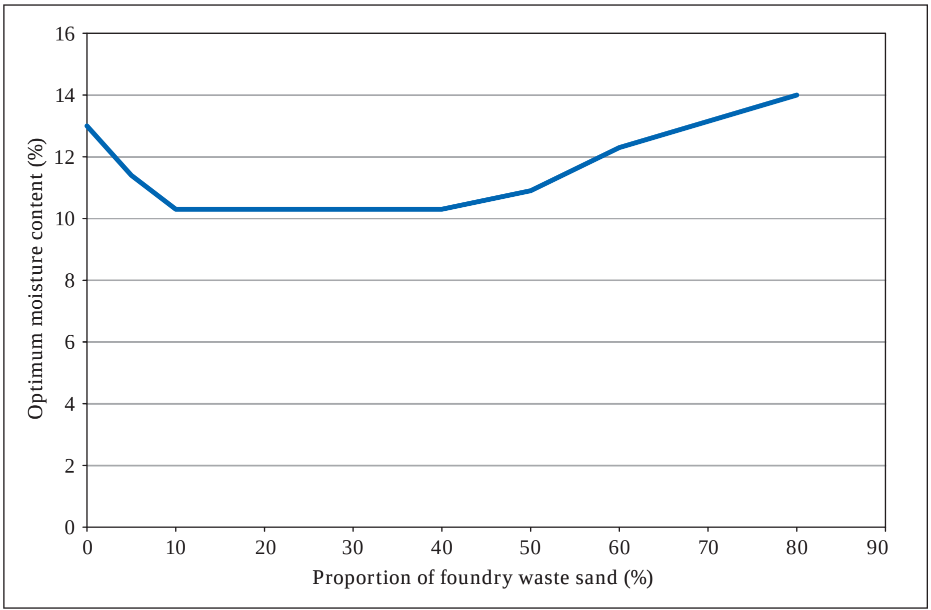

Figure 5 Variation of optimum moisture content with foundry waste sand content

summary of the physical characteristics are given in table 2.

In the absence of technical information from the supplier of the foundry waste sand, it may be surprising at first to note that the foundry waste sand has some plasticity. This is due to the presence of the bentonite clay in the foundry sand (about 10 %, as pointed out by the supplier). The three major components of the foundry sand are uniform high quality quartz sand, cohesive bentonite clay as binder, and coal dust.

The evaluation of the characteristics of leachate from the foundry waste sand was not performed. However, according to the report by FIRST (2004), while the leachate from foundry waste sands may contain trace element concentrations that exceed water quality standards, the concentrations are no different than those from other construction materials.

EXPERIMENTAL RESULTS AND DISCUSSION

Figure 1 shows the influence of the addition of the foundry waste sand in different proportions on variation of the liquid limit and plasticity index. With increasing proportion of the foundry waste sand, there is a marked decrease in the values of the liquid limit and the plasticity index. Figure 2 shows the rate of variation. A significant change in the values of the liquid limit, plasticity index and the linear shrinkage is observed up to about 30 % foundry waste sand added and thereafter the rate of change is slow up to 60 % foundry waste sand addition, followed by a faster rate of change and a slower rate of change again towards 80 % foundry waste sand addition. At 100 %, representing foundry waste sand only, the liquid limit is about 27, with a plasticity index of 7 % and no shrinkage.

Table 3 shows the influence of the proportion of the foundry waste sand on the grading characteristics and the final classification of the mixtures. The results are only for the weathered shale-foundry waste sand mixtures. The influence of the addition of the foundry waste sand is reflected in the change of the classification as well as heave rating. With increasing foundry waste sand proportion, the soil is transformed from clay of intermediate plasticity to a sandy clay. The initial soil classification of A-7-5 and CI changes to A-2-4 and SC. The heave rating improves from a medium rating to a low rating. At least 50 % addition of the foundry waste sand is required for this change to take place.

Figure 3 shows the changes in the swell with increasing content of the foundry sand. The swell in this study refers to the increase in the vertical height of the sample, during the soaking of CBR moulds. The swell percent is reduced from about 6 % to less than 1 % at 80 % foundry waste sand mix proportion.

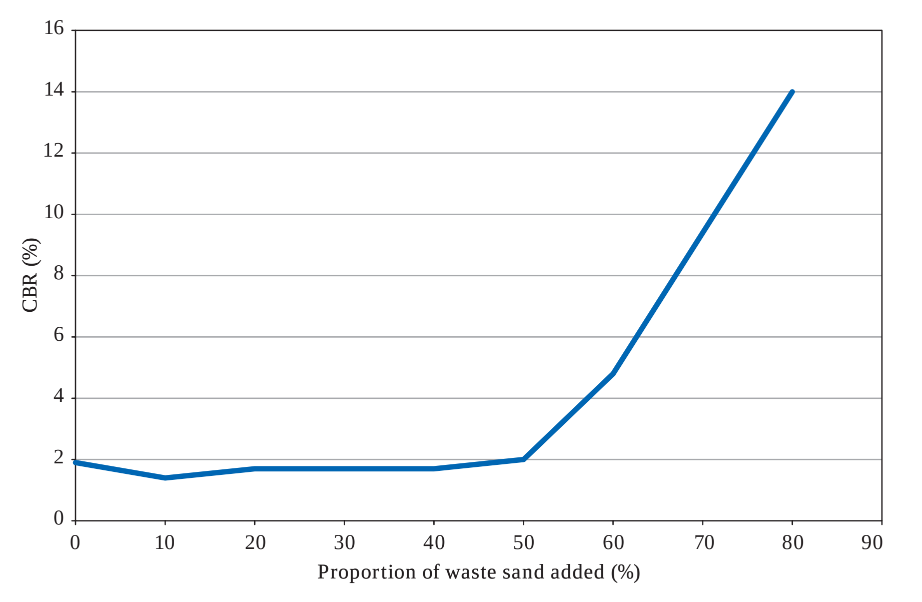

Figure 6 Effect of the proportion of foundry waste sand on the CBR of the weathered shale

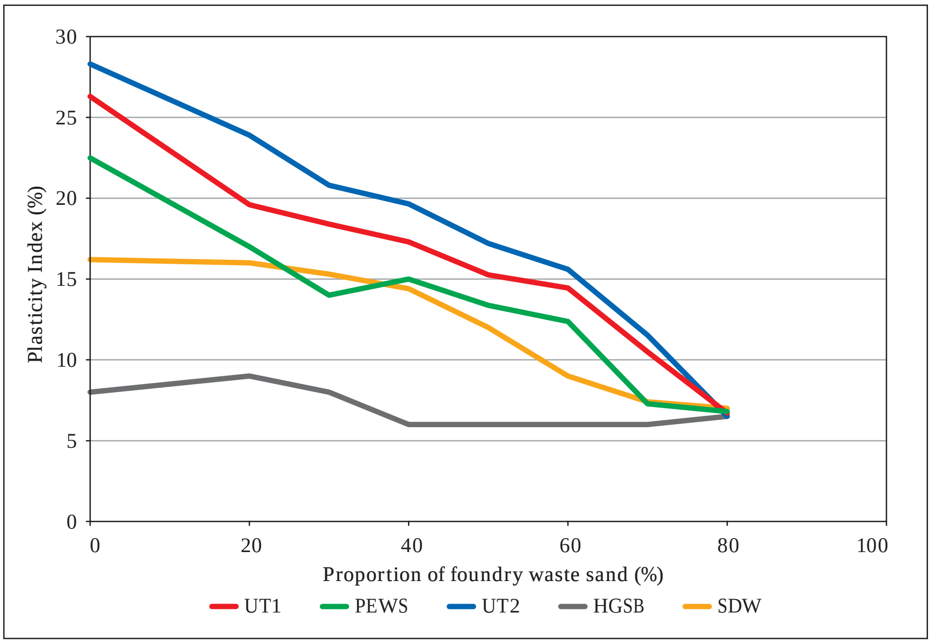

Figure 7 Influence of foundry waste sand proportion on the plasticity index of tested soils

Table 4 Initial values of geotechnical engineering properties of all tested soils and waste foundry sand

Sample	Liquid limit (%)	Plasticity index (%)	Max dry density (kg/m³)	CBR (%)
HGSB	28,0	8,0	No test	No test
PEWS	40,0	22,3	1 898	2
UT1	44,5	26,3	1 785	11
UT2	49,2	28,3	1 815	15
SDW	28,5	16,0	2 001	6
WF sand	26,5	7,0	1 910	19

Figure 4 shows the effect of the proportion of the foundry waste sand in the mixture on the maximum dry density. It can be seen that with increasing foundry waste sand content, the maximum dry density increases with its maximum at about 20 % foundry waste sand content and thereafter decreases with increasing proportion of foundry waste sand. It can be noted in figure 4, that the optimum moisture content initially decreases with increasing foundry waste sand content and remains almost constant at about 10 % up to about 40 % foundry waste sand content. Thereafter the optimum moisture content increases to about 14 % at 80 % foundry waste sand content.

The effect of the addition of foundry waste sand on the CBR is shown in figure 6. There is no significant change in the CBR with an increase in the amount of foundry waste sand up to about 50 % and thereafter there is a noticeable increase in the value of the CBR with increasing foundry waste sand content. A higher proportion of foundry waste sand is therefore required in order to realise the benefits of its use as a stabiliser regarding strength improvement. The CBR results show that the rating of the soil is slightly improved from being rated as poor to a medium rating as a subgrade material when a higher proportion of the foundry waste sand is used.

Further selected tests were then carried out on the other four soil samples. The initial values of the geotechnical properties under investigation are shown in table 4. The results are shown in figures 7, 8 and 9 together with the results of the tests on the weathered shale, sample PEWS.

Figure 7 shows the influence of the addition of the foundry waste sand on the plasticity index of all the tested soils. The plasticity index value of the soil sample HGSB, from Hogsback, only reduced by about 2 % with 80 % mixture of foundry waste sand. On the other hand, in the UT1 sample with an initial PI of 26,3 %, the value reduced to about 7 %, while in the case of UT2 the value reduced from 28 % to 6,5 %. In the case of sample SIDW, the PI reduced from 16 % to about 6,8 %. The overall reduction in the value of the plasticity index varies between 2 % and 21 % for waste foundry sand proportion of 80 %.

The trend shows that the total change, which is an indicator of the effectiveness of the foundry waste sand as a stabiliser, is more apparent in soils with initial high PI and that this depends on the type of soil that the foundry waste sand is mixed with. The higher the value of the initial PI, relative to the initial PI of the waste foundry sand, the higher the rate at which the PI reduces with the addition of waste foundry sand.

Figure 8 shows the effect of the different mix proportion of the foundry waste sand on the maximum density. The results show a mixed trend, seemingly depending on the initial maximum density of the soil, relative to the maximum density of the foundry waste sand. A soil with lower maximum density to that of the foundry waste sand shows an increase of the maximum density with increasing proportion of the foundry sand. A soil with a higher maximum dry density to that of the foundry waste sand shows an initial slight increase in the density followed by a decrease with increasing proportion of the foundry waste sand. The foundry waste sand characteristics become more dominant.

Figure 9 shows the effect of adding the foundry waste sand on the CBR of the soil samples subjected to this test with selected proportions of foundry waste sand, 20 % and 80 %. The overall change in the CBR values is generally less than 10 % at 20 % waste sand proportion. Thus there is in general a

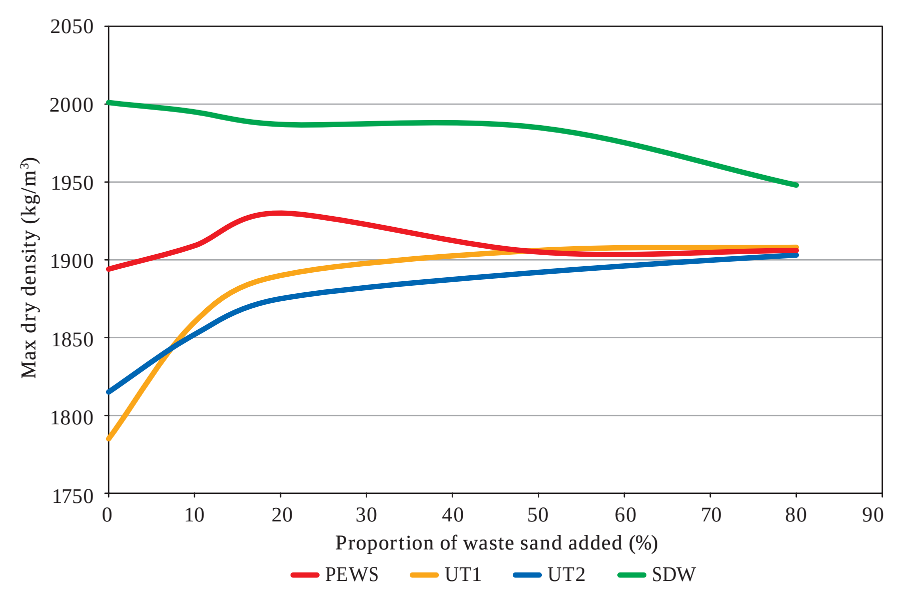

Figure 8 Effect of the proportion of foundry waste sand on the maximum density of tested soils

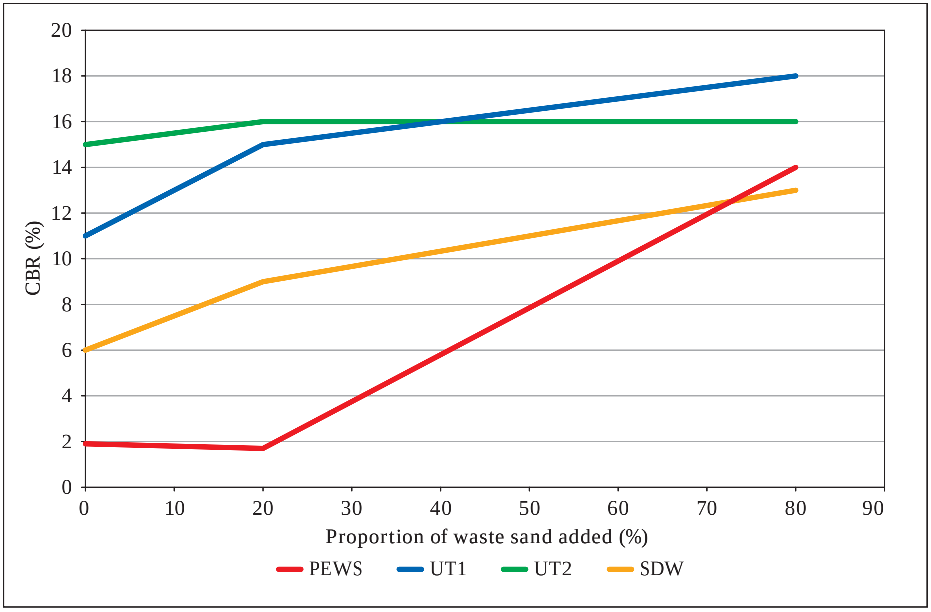

Figure 9 Effect of the proportion of foundry waste sand on the CBR of tested soils

slight increase in the strength property of the soils. The influence on the CBR values, with greater proportion of the waste foundry sand, seems also to depend on the initial CBR values of the soil, relative to the CBR value of the waste foundry sand, which was 19 %. The soil with the lowest initial CBR value shows a significant improvement, but at higher waste foundry sand proportion.

Edil *et al* (2002), in their field study on a variety of industrial by-products as stabilisers, found that foundry sand did not perform as well as the other by-products used in their field tests. They stated that a lower than 10 % content of bentonite could probably make the foundry sand comparatively more beneficial as a stabiliser. The foundry sand in this study had a bentonite content of about 10%. Lower bentonite content in this foundry waste sand or an addition of additives should therefore result in higher increases in strength at lower proportion levels of the waste foundry sand.

DISCUSSION AND CONCLUSIONS

During the study it was established that on average 5–6 t of foundry waste sand is discarded each day from the Port Elizabeth foundry and about 3 000 t of foundry waste sand is annually disposed in waste facilities from a single foundry in the Gauteng area. The utilisation of the foundry waste sand in civil engineering construction, particularly in road construction, whether for temporary works, would be beneficial as it will contribute towards the alleviation of the environmental impact.

There are also economic benefits, from the pavement technology perspective, in that where the soil has been improved by using the foundry sand, the total thickness of the structural elements of the pavement would be reduced. Costs associated with carting away of in-situ material and sourcing from distant locations will be avoided.

While no economic viability analysis was done at this stage of the study, in assessing the economic benefit of using the waste foundry sand in road construction, the cost of preparation, cost of stockpiling, if necessary, and cost of delivery transport as a function of distance from the source of the waste foundry sand to area of application, will be the main contributing factors and should be evaluated. The same consideration applies to other stabilisation additives. In the Port Elizabeth area, for example, cement stabilisation and lime stabilisation costs vary with distance, ranging from about R650/t for cement to about R850/t for lime (at 2004 rates, personal communication). However, waste foundry sand as a recycled material would be cheaper for the same distance.

The influence of the addition of waste foundry sand in different proportions on the characteristics of the weathered shale and other four clayey soils has been demonstrated. It can be observed that there is a significant reduction of the liquid limit, plasticity index and swell with the addition of the foundry waste sand.

The results of the compaction tests demonstrate that changes have taken place and that foundry waste sand slightly improves the physical properties with respect to strength as indicated by the CBR test results. However, a higher proportion of the foundry waste sand, over 50 %, is required to achieve higher increases in load bearing values, for a soil with an initial low CBR value. It is suggested that an addition of small quantities of other additives should significantly increase the achievable strength at lower proportions of the foundry waste sand. The benefit in the mere reduction of the plasticity index achieved at lower proportions of the foundry sand cannot be ignored. It renders the clayey soil easier to handle during construction.

Foundry waste sand has the potential to perform as a mechanical soil stabiliser or can be used for the purpose of soil modification. Consistency in the quality of the by-product may be of concern as any variation in waste management processes could have an effect on the characteristics of the by-product. Investigation into the characteristics of the foundry waste sand from different foundries in the country should be carried out to ascertain the quality and consistency of the by-product.

Further research is also necessary towards increasing the performance and the understanding of the soil-waste foundry sand mixtures in terms of long-term performance under loading. Criteria for determining appropriate mixing rates should be developed from extensive laboratory tests and when possible with demonstration trial sections. This should contribute towards development of applicable specifications for the utilisation of waste foundry sand in road construction in South Africa.

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