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Experimental investigation and field monitoring of recycled material mixtures used for backfilling sewer trenches

Enquête expérimentale et observation sur site de mélanges de matériaux recyclés utilisés comme alternatives pour le remblayage des tranchées d'égout

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ABSTRACT: Blends of recycled materials could be an alternative backfill material in sewer infrastructure as they require less compactive effort to reach the desired relative density and are less sensitive to moisture variations compared to clay backfill. This research investigates the suitability of four blends of recycled materials including recycled glass, recycled plastic, and tire derived aggregates for backfilling excavated trenches located in non-trafficable areas. Specific geotechnical testing procedures were developed to evaluate the behavior of the blends as backfill materials. This included the determination of the self-compactibility of the blends through a modified sand raining technique, investigation of the migration fine particles, and determination of the compressibility of proposed blends using a modified oedometer test. Two blends with the most advantageous properties were selected for the construction of trial sites. These sites were instrumented for deformation and moisture monitoring in comparison with a typical site backfilled with natural soils. The laboratory and field monitoring data presented in this paper are aimed to be a step forward toward the further conservation of natural resources by improving the industry's confidence in using recycled materials.

RÉSUMÉ: Les mélanges de matériaux recyclés pourraient être un matériau de remblayage alternatif dans les infrastructures d'égouts car ils nécessitent moins d'effort de compactage pour atteindre la densité relative souhaitée et sont moins sensibles aux variations d'humidité que les remblais d'argile. Cette recherche examine la pertinence de quatre mélanges de matériaux recyclés, notamment du verre recyclé, du plastique recyclé et des agrégats dérivés de pneus, pour le remblayage de tranchées creusées situées dans des zones non circulables. Des procédures d'essais géotechniques spécifiques ont été élaborées pour évaluer le comportement des mélanges en tant que matériaux de remblai. Cela comprenait la détermination de l'autocompactibilité des mélanges grâce à une technique modifiée de pluviométrie de sable, l'étude des particules fines de migration et la détermination de la compressibilité des mélanges proposés à l'aide d'un test oedomètre modifié. Deux mélanges aux propriétés les plus avantageuses ont été sélectionnés pour la construction des sites de test. Ces sites ont été instrumentés pour la surveillance de la déformation et de l'humidité par rapport à un site typique remblayé avec des sols naturels. Les données de surveillance en laboratoire et sur le terrain présentées dans cet article visent à être un pas en avant vers la poursuite de la conservation des ressources naturelles en améliorant la confiance de l'industrie envers l'utilisation de matériaux recyclés.

KEYWORDS: recycled aggregates, sewer infrastructure, compressibility, trench backfill.

1 INTRODUCTION

Expansive soils are susceptible to significant increase or decrease in volume with changes in the water content. For this reason, geotechnical engineers are facing various challenges in the design of geotechnical infrastructures in expansive soils (Liu and Vanapalli 2019). Sewer infrastructures, especially rigid sewer pipes made of concrete, backfilled with expansive clay are exposed to failure due to unexpected ground movements. This problem is exacerbated in narrow trenches and small diameter sewer pipes located at depths greater than 1.5m where the quality control of the backfilled trenches can be challenging due to safety limitations restricting the field staff from entering the trench for geotechnical testing. A potential solution would be the application of blends of materials that have self-compacting characteristics or require less compactive effort to reach the desired relative density and thus exhibit less settlement on the surface.

Several studies have investigated the suitability of using recycled materials including recycled plastic, glass and tire derived aggregates in civil engineering applications (Imteaz et al. 2012, Landris 2007, Attom 2006, Fauzi et al. 2016, Kamaruddin et al. 2017). However, relatively small proportions of recycled materials have been considered in these studies.

The aim of the current study is investigation of the possibility of utilizing blends of 100% recycled material as sewer trench backfill material to minimize the settlement over the backfilled trench, in particular at non-trafficable areas, which are embedded in expansive clay. The investigation comprises application-specific laboratory testing programs to select the two most appropriate blends for the construction of the trial sites. This paper also presents results of a few months of monitoring settlements and moisture variations of trenches backfilled with the proposed blends of recycled materials in comparison with a site backfilled with conventional backfill material. This research can introduce a new destination for existing stockpiles of waste or recycled materials, in particular, recycled plastic, glass and tire; and will create a market for sustainable use of these waste streams.

2 METHODOLOGY

2.1 *Materials*

Recycled materials used in this study including recycled glass (RG), recycled plastic (RP) and tire derived aggregates (TDA) were supplied from local recycling facilities in Victoria, Australia. Four blends with various percentages of RG, RP and TDA contents with gradation curves within Class 4 upper and lower band gradation of VicRoads (2013) as recommended by Melbourne Water Retail Agencies' Backfill Specifications (MRWA (2013)) were selected as shown in Figure 1.

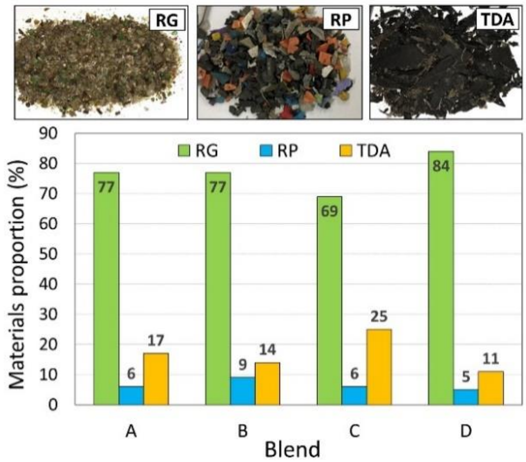

Figure 1. Recycled materials ratios in Blends A, B, C and D

2.2 *Compaction using sand-rain technique*

Air-pluviation (also known as sand-rain compaction, SRC) is a desirable approach to obtain uniform, identical and high-density granular material specimens (Lagioia et al. 2006, Tabaroei et al. 2017). In this research, an SRC set-up was developed to simulate backfilling of a trench using an excavator bucket. The set-up consisted of a beam, hanging rod, hopper, collection tank and sample collecting mold (Figure 2).
The cross-section of the hopper from the top was 0.2m in length and 0.2m in width. The short and long heights of the hopper were 0.2 m and 0.45 m, respectively. A lid that opened up to 50mm was provided at the bottom of the hopper. The hopper could move horizontally along the beam and vertically by adjusting the height of the beam and the hanging rod. The mold with 0.15 m diameter and 0.18 m height was placed in a tank so that materials that dropped out of the mold could be collected. The base of the mold had 2mm through holes to allow drainage. The position of the hopper was adjusted to achieve the height of drops (HD) of 0.5 m to 2 m. During the raining process, the hopper was moved back and forth horizontally within a distance of approximately 400 mm to ensure that the density at the edge of the mold was the same as the center. Blends were prepared at moisture contents varied from 3% to 18 %, and dropped through the hopper into the mold.

For moisture contents (MC)>12% and after dropping, the blend was left in the mold for 15 minutes to allow the drainage and the dry density (DD) corresponding to the post-test MC was obtained. The post-test MC could be considered as "field capacity" at which no extra water was drained off the sample due to gravity. This procedure was repeated at various MCs and HDs.

Using the maximum dry densities (MDD) obtained from SRC and maximum/minimum index densities achieved from the procedure described in ASTM-D4254 (2016) and ASTM-D4253 (2016), the capability of using SRC to achieve a relative density higher than 80% was investigated. Relative densities>80% were addressed to correlate with the relative modified Proctor compaction>95% (Look 2014) which is typically the minimum requirement for fill earthworks in non-trafficable areas.

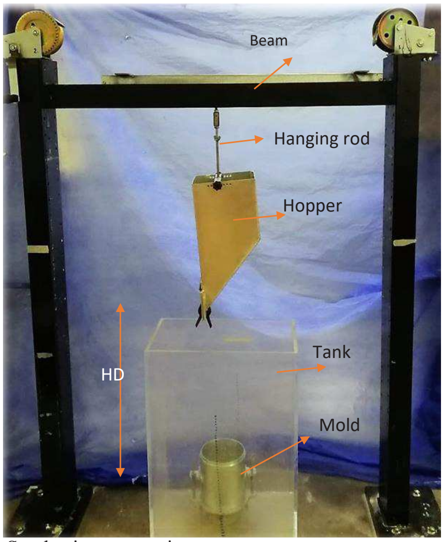

Figure 2. Sand-rain compaction setup

In addition, the standard proctor compaction test was carried out to determine the optimum moisture contents (OMCs) and MDDs for all blends to be compared with the corresponding OMCs and MDDs obtained through the SRC.

2.3 *Modified oedometer test*

The compressibility of the blends was studied following the ASTM-D2435/D2435M (2011) procedure with modifications to the mold size and compaction of the sample. A sample prepared at a target MC was placed in a mold of 150 mm diameter in three layers to achieve a target DD at a height of 75mm. The base of the mold was provided with 2 mm through holes to allow drainage. Filter papers were used at the top and bottom of the sample. Loading stages of 6, 12.5, 25, 50, 100, 200 kPa were applied to an unsaturated sample and at each loading step, the settlement was recorded. Once the change in the deformation became negligible, which took approximately 20 minutes, the next loading step was applied. At the end of the test, the axial strain-stress relationship was plotted.

2.4 *Segregation test*

This test was carried out to investigate the migration of finer particles within the blends by simulating migration of fine particles due to precipitation. This was achieved by measuring settlement and comparing the particle size distributions (PSD) of the blend before segregation testing with the PSD of the top, middle and bottom layers after simulating the precipitation. A cylinder of 255 mm diameter and 315 mm height was used. The base of the cylinder had 2 mm holes to allow drainage. A sheet of geotextile with 0.08 mm openings was placed on the base to avoid losing fine particles or/and clogging the holes. Then three identical mixes were placed sequentially to fill a height of 300 mm and achieve the target density. The top-level of each layer was marked on the Perspex cylinder to allow the separate collection of the 3 layers. Another sheet of geotextile was placed on the top of the sample. A steel plate with 2 mm holes was then placed on the geotextile which applied a negligible pressure of 0.17 kPa on the surface of the sample. Three dial gauges were set on the top of the steel plate to measure settlements due to watering. During the watering stage, the reading of settlements was monitored and the watering was stopped once the reading was kept constant. The sample was left to drain and reach the field capacity and from several trial tests, it was noticed that adequate time to reach the field capacity was about 45 minutes. The average settlement was then calculated. Next, the top, middle and bottom layers were collected in three separate trays and left in an oven for 48 hrs at a temperature of 50°C. The post-test moisture content, which represents the field capacity, was calculated and the PSD for each layer was obtained. Finally, the PSD of each layer was compared with the original PSD of the blend and the finer particle migration was investigated.

2.5 *Construction and instrumentations*

The two most appropriate blends (Blends B and D) proposed based on experimental results were used for the construction of full-scale trial sites. For the construction, the proposed blend was placed around the manhole and extended approximately 5 m in the trench on one side of the manhole structure (Figure 3). The bottom 1 m of the trench, embedment zone where the pipe was placed, was backfilled with standard crushed rock. Above the embedment zone, the trench was backfilled with proposed blends of recycled materials except for the top 0.5m that was backfilled with site-won clay and compacted using the excavator's compaction plate. The other side of the manhole structure in the trench was backfilled with site-won clay. The average liquid limit, plastic limit and plasticity index of the site-won soils were 61%, 30% and 31%, respectively, indicating the soil was clay with high plasticity. The site-won clay also included up to 15% by mass of basalt boulders and cobbles.

Both sides of the manhole structure were instrumented using settlement plates to monitor deformation changes using surveying techniques and moisture sensors to monitor moisture variations in depth of the backfilled area due to precipitation. The moisture sensors were connected to a data acquisition unit located on the surface which settlement data could be collected in each site visit. The effect of moisture variations on the natural ground movement have been monitoring by installing moisture content sensors at depth of 0.5m, 1m and 1.5m from ground level.

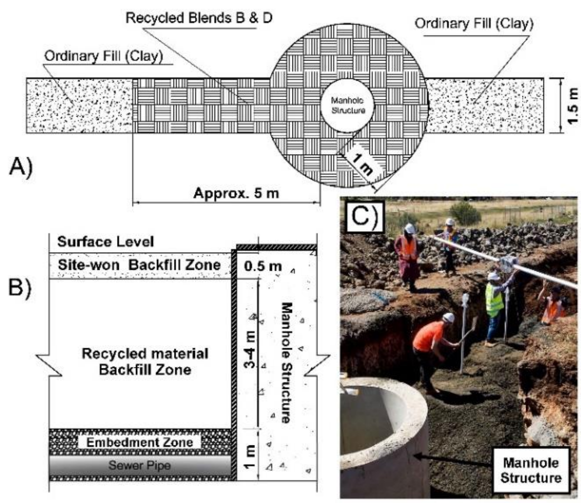

Figure 3. Schematic (a) plan & (b) elevation view of the trial site and (c) installation of moisture sensors and settlement plates in the trench

3 RESULTS AND DISCUSSIONS

3.1 *Particle size distribution*

The PSD of the blends as shown in Figure 4 indicates that all blends almost fell within the Class 4 gradation, as recommended by MRWA (2013) on the coarse side; however, they are slightly outside the lower limit on the fine side of the curve.

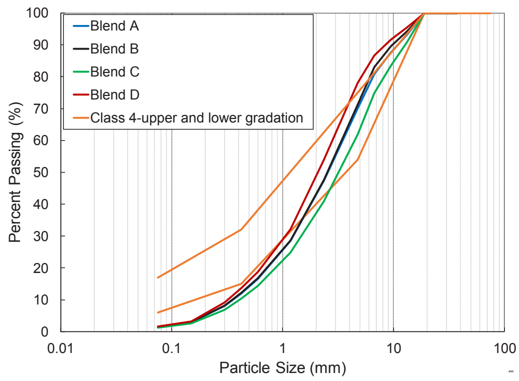

Figure 4. Particle size distribution of the four blends

3.2 *Compaction test results*

The OMC and MDD obtained from standard Proctor compaction (ASTM-D698 2012) are presented in Table 1.

Table 1. OMC and MDD obtained from standard Proctor compaction

Blend	OMC (%)	MDD (t/m^3)
A	8.5	1.34
B	9.5	1.36
C	11	1.25
D	7.9	1.37

From SRC results, post-test moisture content (P-MC) and dry density (DD) relationships at various height of drops (HDs) were obtained for all blends. Figure 5 shows that the DD of Blend D (as an example) increased as HD increased and maximum densities were achieved at HD of 2m and this behavior was observed for other blends. The values on the plot show the pre-test MCs (%) for HD=2000 mm samples.

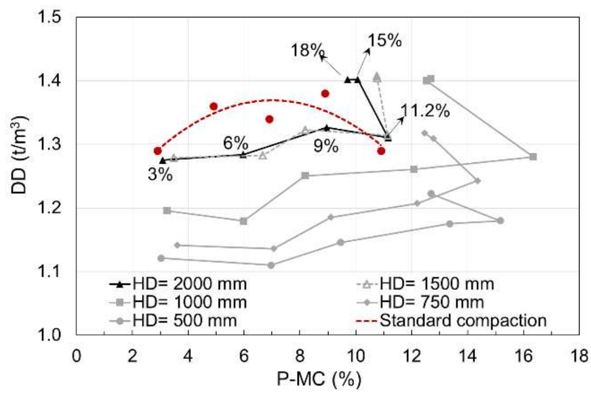

Figure 5. DD and P-MC relation at different HD for Blend D

Table 2 presents P-MC and DD for Blends A, B and C at the HD of 2 m while Figure 5 provides these information for Blend D. Figure 5 and Table 2 show that at a constant HD, the DD decreased as P-MC decreased. For initial MCs>12%, after dropping, the water drained from the sample and resulted in a P-MC between 9% and 12.7%. As an example, Blend D was prepared at MC of 15% and was dropped from HD = 2 m. The blend was left for 15 minutes for draining until no further drainage occurred, and the P-MC was measured to be 10.1%. For samples prepared at MCs >12%, the combined effect of water acting as a softening agent and greater densification led to a greater drainage. This resulted in turning the compaction curve in the opposite direction and thus, for the same P-MC, two values for DD were achieved. The lower DD was corresponding to the lower initial MC with no drainage and the higher DD was corresponding to the higher initial MC reduced through drainage to reach the P-MC, as indicated in Figure 5.

Table 2. DD and P-MC relations for Blends A, B and C at HD of 2m

Blend	Initial MC (%)	P-MC (%)	DD (t/m^3)
A	3.0	3.0	1.22
	6.5	6.5	1.20
	8.5	8.5	1.21
	11.6	11.6	1.22
	15.0	9.0	1.25
	18.0	9.2	1.30
B	3.0	3.0	1.15
	5.0	5.0	1.18
	8.5	8.5	1.19
	10.5	10.5	1.20
	15.0	9.7	1.35
	18.0	10.0	1.36
C	3.0	3.0	1.07
	6.5	6.5	1.05
	8.5	8.5	1.06
	11.5	11.5	1.07
	15.0	10.3	1.13
	10.0	10.1	1.13

The compaction results showed that the OMCs and MDDs in SRC method were obtained by preparing blends at high MCs (≥15%) and dropping from HD = 2 m. The OMCs and MDDs were determined to be (18%, 1.3 t/m^3), (15%, 1.35 t/m^3), (15%, 1.13 t/m^3) and (18%, 1.4 t/m^3) for Blends A, B, C and D, respectively. The P-MCs were 9.2%, 9.7%, 10.3% and 9.7% for Blends A, B, C and D, respectively. Interestingly, the MDD obtained through the SRC for Blends A, B, C and D were about 97%, 99.3%, 90.4% and 102.2% of the corresponding values obtained from the standard Proctor compaction (SPC). The relative densities (RD) with respect to maximum/minimum index density test results were greater than 80% for Blends A, B and D, being 82.5%, 85.5% and 83.5%, respectively (Figure 6). However, the RD of Blend C obtained through SRC was 52% which was significantly lower than the other blends. Therefore, Blend C was considered unsuitable for the construction of the trial site.

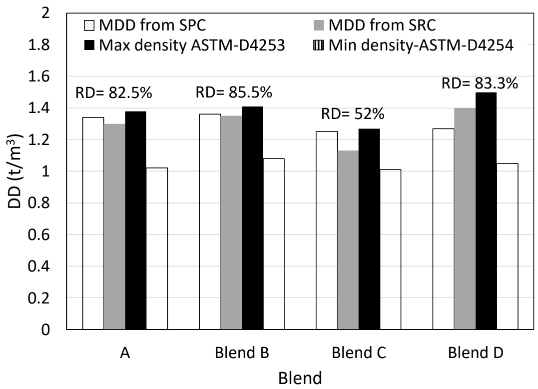

Figure 6. Relative densities based on the MDDs achieved by SRC

3.3 *Compressibility test results*

The modified 1-D oedometer test was conducted to select the two most appropriate blends among Blends A, B and D. Specimens were prepared at the OMC and MDD obtained from the SRC. The results shown in Figure 7 indicate that in general, the total axial strain achieved in Blend A was higher than that of Blends B and D. Consequently, Blends B and D were selected for the construction of the trial site.

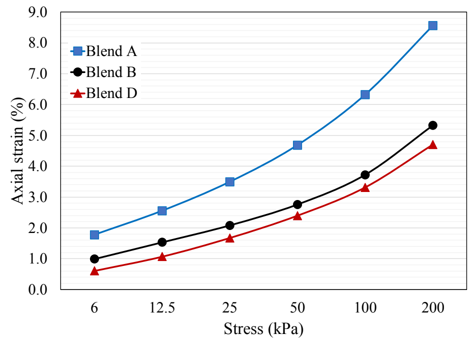

Figure 7. Axial strain vs stress for Blends A, B and D at OMC and MDD

It is important to note that the density achieved through SRC is the loosest state in the backfilling process. During backfilling, the surcharge of the upper layers causes further densification of the bottom layers and the surface of the backfilled area can be compacted using the excavator's compaction plate. Therefore, it is expected that the final density of the blends falls between the DD achieved at MC of 9.7% (1.2 t/m^3 and 1.33 t/m^3 for Blends B and D, respectively) and those achieved at MC≥15%. Further compressibility assessment was carried out on Blends B and D prepared at MC of 9.7% and DD lower than the MDD obtained from SRC as shown in Figure 8. For Blend B, blends prepared at DD higher than 1.2 t/m^3, the change in axial strains obtained due to applying a stress up to 50 kPa was negligible (Figure 8). Assuming a maximum density of 1.41 t/m^3 and a depth of 4m, the maximum surcharge at the bottom of the backfilled area was estimated to be 55kPa. The axial strain obtained by loading Blend B sample prepared at DD of 1.2 t/m^3 was considerably higher than that of the other blends. Considering the backfilling process, the DD was expected to increase from 1.2 t/m^3 to at least 1.25 t/m^3. For Blend D, the change in axial strain between the two samples under a stress less than 100 kPa was minor. As the bottom of the recycled material backfill zone is at a depth of about 4m and assuming the maximum density of 1.50 t/m^3, the maximum surcharge could be calculated to be 59kPa (<<100kPa). Thus, MC=9.7% and DD=1.25 t/m^3 and 1.33 t/m^3 for Blends B and D, respectively were suggested for the trial construction.

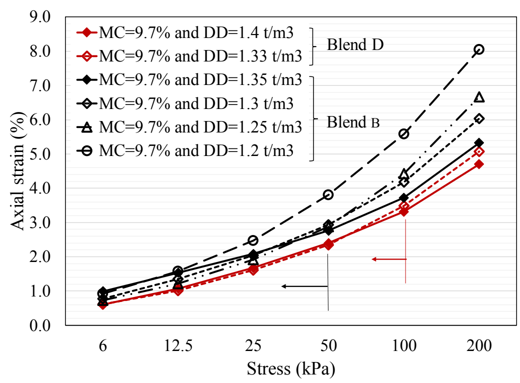

Figure 8. Axial strain vs stress for Blends B & D at DDs ≤ MDD

3.4 *Segregation test results*

To investigate the impact of sample MC and HD on the amount of settlement achieved on the backfilled trench through the migration of fined due to precipitation, two different MCs and two different HDs were considered for testing. First, the segregation test was carried out on Blends B and D prepared at the MC of 2.3% (as-received MC) and dropped from HD = 0.6 m (typical HD during construction) which consequently achieved DDs of 1.10 t/m^3 and 1.12 t/m^3 for Blends B and D, respectively. Next, the segregation test was carried out on blends prepared at the selected MC and DD as shown in Table 3. At end of the test, the samples were left for 45 minutes to drain and reach the field capacity and the final settlements were recorded.

Table 3. Segregation test results

Blend	B		D	
MC (%)	2.3	9.7	2.3	9.7
Axial strain (%)	13.7	0.07	17.3	0.03
Field capacity (%)	8.2	9.3	9.0	9.5

The results presented in Table 3 show that significant settlements reduction was obtained due to the increase in MC from 2.3% to 9.7% and HD from 0.6 m to 2 m and consequently the DD increased from 1.10 t/m^3 and 1.12 t/m^3 to 1.25 t/m^3 and 1.33 t/m^3 for Blends B and D, respectively. The axial strain decreased from 13.7% to 0.07% for Blend B and from 17.3% to 0.03% for Blend D. Interestingly, the axial strains resulted from preparing Blends B and D at the MC of 9.7% were close to zero, thereby, it was expected that no considerable segregation occurred for Blends B and D samples prepared at the MC and DD achieved through the SRC (Table 4 presents Blend D as an example).

Table 4. PSD for Blend D

Size (mm)	Percent Passing (%)			
	Top	Middle	Bottom	Pre- test Blend D
19	100.0	100.0	100.0	100.0
9.5	92.2	92.4	92.5	91.3
6.7	87.4	88.2	85.7	85.2
4.75	79.8	78.	75.2	77.2
2.36	56.6	56.8	53.4	54.3
1.18	31.3	32.4	31.6	30.8
0.6	18.7	18.8	18.6	19.1
0.425	14.7	15.3	15.0	13.1
0.3	9.6	9.5	10.0	8.8
0.15	2.8	2.6	4.0	3.7
0.075	1.2	0.9	1.8	1.5

3.5 *Settlement and moisture monitoring results*

Monitoring of moisture content changes and ground deformations using settlement plates for Blends B and D were carried out from October 1st, 2020 to February 9th, 2021 for Blend B (Figures 9a and 10a) and from November 26th, 2020 to February 9th, 2021 for Blend D (Figures 9b and 10b). In the first month after the construction, data collection was carried out once a week and thereafter once a month. Figure 10 shows less deformation in trenches backfilled with recycled materials compared to those backfilled with site-won soils during the data collection period. The presence of boulders and cobbles in clay backfill could have contributed to less deformation than expected.

Figure 9a shows that despite the significant difference in moisture contents at different depths, MC values move towards an equilibrium and get closer to each other at different depths as long as no heavy rain was detected. A similar trend was expected in the site constructed using Blend D (Figure 9b).

The rain events (Figure 11) was the main factor affecting the MC variation while the temperature (Figure 12) was the second factor that affected the MC of the top layer (sensor at 0.5 m depth). The rain and temperature data were obtained from the Australian Bureau of Meteorology climate database (http://www.bom.gov.au/climate/data/). As an example, Figure 9a showed that MC of Blend B at various depths decreased to approach each other during the period starting from Oct 1st to Oct 20th. During this period, Figure 11 shows that no heavy rain was detected and a moderate temperature (15°C-24°C) was recorded. As another example, from Nov 19th to Nov 25th, an increase in MC was noticed at depths of 1m and 1.5m due to heavy rain on Nov 23rd (39.2 mm). However, the MC at depth of 0.5 m decreased as the temperature increased on the day of 25 Nov to about 31°C.

It should be noted that the MC sensor located at the depth of 0.5m was at the border between recycled material (with MC of 9.7%) and clay backfill (with MC of 30.2%). In reality, during compaction, the clay layer could be pushed further down to touch the sensor and consequently this sensor detected a MC (24.1%) ranging between 9.7% and 30.2%.

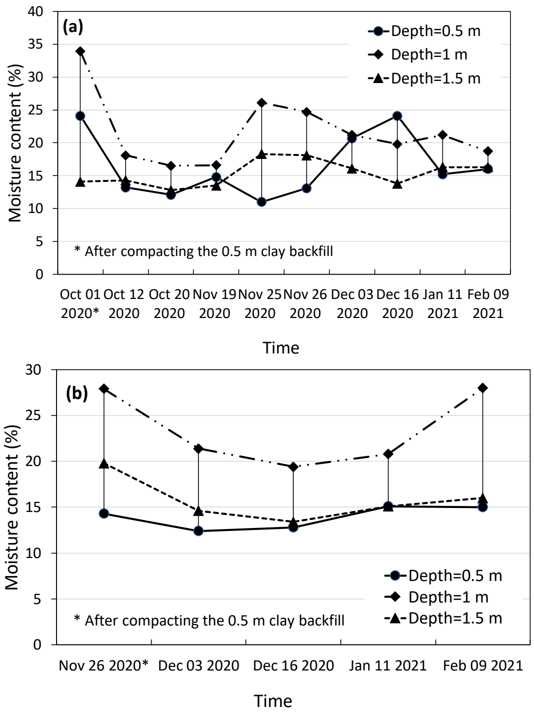

Figure 9. MC monitoring results for (a) Blends B and (b) Blend D

4 CONCLUSIONS

Laboratory tests including sand-rain compaction and modified oedometer tests were carried out on four recycled material blends to select the two most appropriate ones for the construction of trial sites. Results showed an increase in dry density due to increased MC and height of drop (HD). The MDD was achieved by preparing a blend at a MC ≥15% and after dropping the blends from a height of 2m. At high MCs, the MDD obtained through the sand-rain compaction approached the corresponding values obtained from the standard Proctor compaction and achieved >80% relative density. Both Blends B and D mixed at the MCs corresponding to their field capacity and HD of 2m are recommended for construction purposes.

Data achieved through 4 months of field monitoring of the constructed and instrumented trial sites indicated less surface deformation in trenches backfilled with recycled materials. The field monitoring will continue for a period of 2 to 3 years to investigate a longer term performance of the backfilled trenches. The moisture content monitoring data indicated that rainfall was the main factor that affected the moisture content changes at different depths. However, the high temperature variations affected the moisture content changes close to the surface. In spite of significantly higher MC values at depths of 1.0 and 1.5 m for 2-3 months after construction, these values eventually became closer to each other to reach an equilibrium.

The outcomes of this project are expected to promote sustainable construction approaches and the utilization of recycled geomaterials in geotechnical projects.

A recommended future research is investigating the potential for the bridging effect in narrow trenches where granular fill can create arching between trench walls, which settles over time.

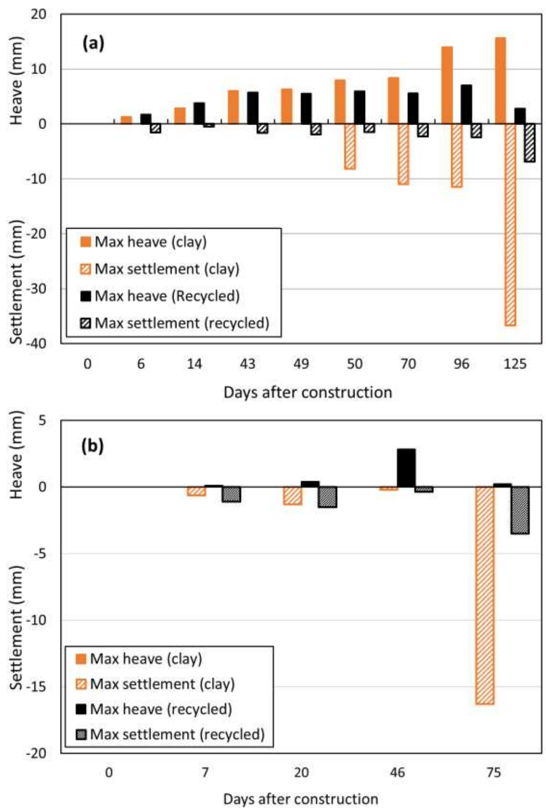

Figure 10. Ground deformation for (a) site 1 and (b) site 2

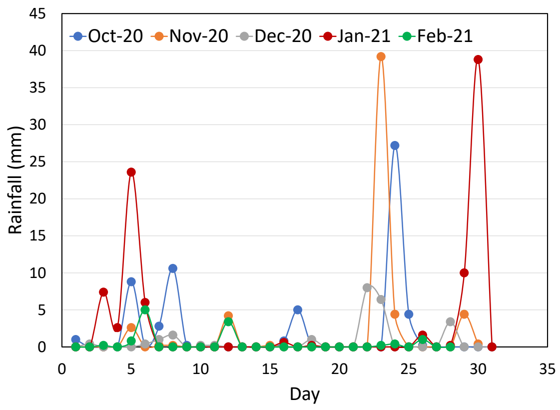

Figure 11: Rainfall data starting from Oct 2020 to Feb 2021

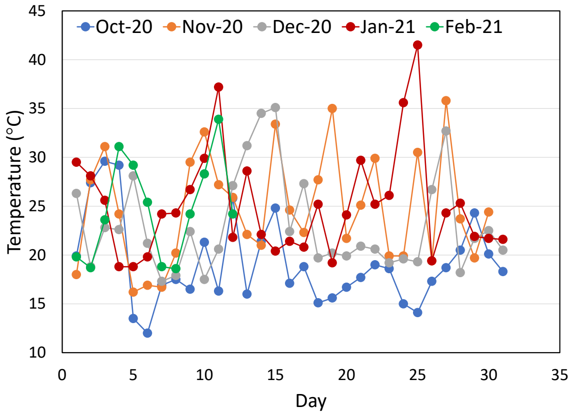

Figure 12: Temperature data starting from Oct 2020 to Feb 2021

5 ACKNOWLEDGEMENTS

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