

BACKFILL GROUT A-LIQUID, BACKFILL GROUT, METHODS OF MAKING AND USE THEREOF

The invention relates to a backfill grout A-liquid. The invention also relates to a
5 method of preparing an A-liquid for backfill grout. The invention also relates to use of a backfill grout. These

The invention has particular, but not exclusive, application for the preparation of backfill grout for use in tunnel boring machine (TBM) applications.

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Grout is a construction material used for multiple purposes including filling of tail voids. Just one application where grout is used is for the "backfilling" of tail voids in tunnel boring machine (TBM) applications. A tunnel boring machine is a machine used to excavate tunnels, typically with a circular cross section, through a variety of
15 soil and rock strata. Modern tunnel boring machines typically consist of a rotating cutting wheel, called a cutter head, followed by a main bearing, a thrust system and trailing support mechanisms. The type of machine used depends on the particular geology of the project, the amount of ground water present and other factors.

20 Generally, backfill grouting is compulsory during tunnel boring machine driving in order to prevent ground settlement. Two types of tunnel boring machines commonly used are Earth Pressure Balance Machines (EPB) and Slurry Type Machines. The earth pressure balance machine gets its name because it is capable of holding up ground by maintaining a balance between earth and pressure. The tunnel boring
25 machine operator and automated systems keep the rate of soil removal equal to the rate of machine advance to maintain a stable environment. In addition for EPB, additives such as bentonite or foam agent are injected into the ground for stabilisation.

In soft ground conditions and in rock condition with high water pressure, Slurry Type tunnel boring machines are needed. These machines offer an enclosed working environment. Soils are mixed with bentonite slurry, which must be removed from the tunnel through a system of slurry pipes that exit the tunnel. Large slurry separation plants are needed on the surface for this process, which separate the dirt from the slurry so it can be recycled back into the tunnel.

The backfill grout material used normally consists of an A-liquid and a B-liquid, made to shot just before being ejected from the tail void of the tunnel boring machine.

Liquid A generally comprises: cement (provided as a stiffening agent); a stabiliser (which acts to retard grout material hardening, and may including a foaming agent); bentonite – mentioned above – is provided as a binding agent (preventing the separation of the components in the liquid); and water. Liquid B generally comprises sodium silicate.

One possible mix of these components is given in Table 1 below

	Component	Amount	Unit Price	Percentage of Grout Make up
A-liquid	Cement	250 KG	SGD 110/tonne	40.53
	Bentonite	30 KG	SGD 270/tonne	11.94
	Stabiliser	2.5 L	SGD 2/KG	7.37
	Water	824 L	SGD 2/m ³	2.43
B-liquid	Sodium silicate	80 L	SGD 320/tonne	37.73

TABLE 1

The invention is defined in the independent claims. Some optional features of the invention are defined in the dependent claims.

Provision of a backfill grout with an A-liquid having a binding agent comprising marine clay, or use thereof, offers significant benefits in comparison with conventional techniques. For instance, excavation of bentonite is a destructive

procedure, not being environmentally friendly, and placing onerous requirements on the environment. Further, and as can be seen above, bentonite is an expensive material.

- 5 Replacement of the bentonite in the A-liquid, whether in part or in full, with a binding agent comprising marine clay is an environmentally friendly construction method, offering significant cost savings. The new grout material may have the same performance of the existing backfill material including the physical characteristics such as specific gravity and viscosity.

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Furthermore, marine clay is a commonplace material, currently excavated and used in numerous construction projects, although it is currently transported away for disposal being generally considered an undesirable by-product of the construction and excavation process. In, for example, Singapore, numerous major construction projects such as the ongoing extension of the Mass Rapid Transport (MRT) system has resulted in major excavation projects for the construction of the new subway lines. In Singapore, any excavated marine clay (and also fluvial clay) are considered waste products having no further desirous usage. These are disposed at Land Transport Authority (LTA) dumping grounds. This in turn requires a significant effort.

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Numerous transportation lorries are required to collect the excavated clay material, and transport it by road to the dumping ground, where they typically have to wait for lengthy periods in queues with many other lorries in order to dump the clay material. As a result, productivity of the excavation works is not particularly efficient, and it is considered in some circles to have become a serious social problem.

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Further, and again using Singapore as an example, slurry type tunnel boring machines were adopted for the first time in the construction of the Singapore MRT Circle Line in 2003.

In the slurry type tunnel boring machine technique, excavated soil is changed to slurry in the chamber of the tunnel boring machine during excavation. The slurry is transported to ground level by a slurry transportation system. Transported slurry is separated in a slurry treatment plant, according to pre-defined grading. For example, 5 gravel is separated from the transported slurry by a gravel separator, with sand being separated out by a sand separator as well.

Usually, at least a portion of this gravel and sand accumulates in a soil pit, for later loading to a lorry again for disposal at a dumping ground without any processing. On 10 the other hand, a part of the slurry may be reused in the tunnel boring machine, carried to a surplus slurry tank where poly-aluminium chloride is added. After that, the mixture of surplus slurry and poly-aluminium chloride is dried by a filter press. Finally, the dried cake is also disposed at the dumping ground, being considered an unsuitable soil.

15 However, the Applicant has realised that marine clay has properties which make it a suitable candidate as a replacement, whether in part or in full, for bentonite in the backfill grout material. That is, the marine clay is actually a recyclable material that can be used to minimise environmental destruction caused by excavation bentonite, and offer significant cost savings. As can be seen from Table 1, bentonite is an 20 expensive material. Further, the re-use of marine clay excavated in the excavation process can almost immediately be recycled, at least in some instances, thereby obviating the onerous requirement of having to transport and dispose the excavated marine clay, as described above.

25 So, in a first implementation, there is provided a backfill grout A-liquid having a binding agent comprising marine clay. Also, the techniques disclosed herein extend to a method of preparing an A-liquid for backfill grout, the method comprising including marine clay in the A-liquid as a binding agent. The techniques disclosed

herein also extend to use of marine clay as a binding agent in an A-liquid for a backfill grout.

The invention will now be described by way of example only. Reference is made to
5 the accompanying drawing in which:

Figure 1 is a graph illustrating specific gravity and viscosity properties of exemplary slurries.

The marine clay can be used to replace the bentonite as the binding agent in the A-
10 liquid, in part or in full. It may be preferable that the marine clay replaces the bentonite in full, such that the binding agent has no bentonite. That is, it may be preferable the binding does not comprise bentonite (at least not in any substantial or significant amount, and potentially not at all).

15 Typically, the binding agent is in slurry form, where the slurry comprises the marine clay. The Applicant has found that an acceptable range for specific gravity of the slurry is between 1.01 and 1.23. Further, the Applicant has found that an acceptable range for Marsh funnel viscosity of the slurry is between 19 seconds and 40 seconds.

20 More preferable ranges of specific gravity may be:

- between 1.03 and 1.20;
- between 1.05 and 1.17;
- between 1.07 and 1.14 (the Applicant has found this to be a particularly preferable range);
- 25 • between 1.09 and 1.12.

Of course, other ranges of this order are also envisaged.

More preferable ranges of Marsh funnel viscosity may be:

- 30 • between 19.25 seconds and 35 seconds;

- between 19.50 seconds and 30 seconds;
- between 19.75 seconds and 25 seconds
- between 20 seconds and 22 seconds (the Applicant has found this to be a particularly preferable range).

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Figure 1 is a graph illustrating a plot 100 of specific gravity values 102 (on the X-axis) against viscosity 104 (on the Y-axis) for slurries. As noted above, the Applicant has found that an acceptable range for specific gravity of the slurry is between 1.01 (reference 106 in Figure 1) and 1.23 (reference 108 in Figure 1). Further, the Applicant has found that an acceptable range for Marsh funnel viscosity of the slurry is between 19 seconds (reference 110) and 40 seconds (reference 112).

The Applicant's particularly preferable range of specific gravity for the slurry is between 1.07 (reference 114 and Figure 1) and 1.14 (reference 116 and Figure 1). The Applicant's particularly preferable range for Marsh funnel viscosity is between 20 seconds (reference 118 in Figure 1) and 22 seconds (reference 120 and Figure 1).

Generally speaking, the techniques disclosed herein are applicable with slurries having properties across the declared ranges. The precise values of specific gravity and Marsh funnel viscosity of the slurry may be variable in between these ranges, such that the specific gravity is variable (or generally variable) in direct proportion with variations in the Marsh funnel viscosity value. That is, if the specific gravity of the slurry increases above 1.01, a corresponding increase in Marsh funnel viscosity will ensue, as illustrated in Figure 1. Of course, any variation may be within industry-standard acceptable tolerances. The techniques described herein are such that an increase in the specific gravity above 1.01 results in a corresponding increase in the Marsh funnel viscosity above 19 seconds.

In some arrangements, the marine clay comprises particles of not more than 0.063 mm in diameter. The slurry may be fully mixed in advance and the marine clay may

have been subjected to filtration in accordance with the 0.063mm filter specified by BS1377 such that the marine clay particles, and the silt particles (if any) are not more than the stated diameter. As such, this may facilitate operation of any items of machinery – such as pumps and agitators.

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Thus, a backfill grout may comprise the A-liquid as described above. The backfill count comprises an A-liquid including cement, stabiliser and the slurry having the marine clay, provided as a binding agent and a B-liquid comprising sodium silicate.

- 10 Table 2 illustrates four exemplary backfill grouts each having a volume of 1000 L, and the respective properties of the grouts using a binding agent comprising marine clay.

<u>Grout Property</u>	<u>Unit</u>	<u>Grout 1</u>	<u>Grout 2</u>	<u>Grout 3</u>	<u>Grout 4</u>
Cement Weight	Kg	250.000	270.000	250.000	270.000
Cement Density	kg/L	3.150	3.150	3.150	3.150
Cement Volume	L	79.365	85.714	79.365	85.714
Stabilizer Weight	Kg	2.400	6.000	2.400	6.000
Stabilizer Density	kg/L	1.200	1.200	1.200	1.200
Stabilizer Volume	L	2.000	5.000	2.000	5.000
Sodium Silicate Weight	Kg	97.300	139.000	97.300	139.000
Sodium Silicate Density	kg/L	1.390	1.390	1.390	1.390
Sodium Silicate Volume	L	70.000	100.000	70.000	100.000
Slurry Volume	L	848.635	809.286	848.635	809.286
Slurry Specific Gravity (Density)	kg/L	1.070	1.070	1.140	1.140
Specific Gravity of Soil	kg/L	2.700	2.700	2.700	2.700
Void Ratio		23.286	23.286	11.143	11.143
Weight of Soil (Actual)	Kg	94.348	89.974	188.696	179.947
Marine Clay Weight (Nature Condition, Assume w=70%)	Kg	160.392	152.955	320.784	305.910
Weight of Water	Kg	747.647	712.981	646.660	616.676
Total Volume	L	1,000.00	1,000.00	1,000.00	1,000.00

TABLE 2

In the above table, the exemplary grouts are given with a minimum weight of cement of 250 kg and the maximum weight of 270 kg, but the Applicant envisages other grout materials having other weights of cement therein, including weights in the range between 250 kg and 270 kg. However, in order to achieve a preferable long-term strength of 2 MPa for 28 days, cements in the range of 230 to 300 kg per cubic metre may also be used. The cement used in the backfill grout may be a readily-obtainable cement such as Portland Cement, but may also use PBFC cement to increase long-term strength.

Similar comments apply concerning the amount of stabiliser, sodium silicate, marine clay and water, we have in the above examples the lower and upper values of preferred ranges are given. Thus, in the examples, the amount of stabiliser used may be between 2 L and 5 L. The amount of sodium silicate used may be between 70 L and 100 L. The amount of marine clay (in its natural condition, assuming the water content of the marine clay to be 70%) may be between 150 kg and 320 kg. The amount of water may be between 600 kg and 750 kg (although this may alternatively be expressed in litres).

The calculation of the void ratio is given according to the following equation:

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$$(G_s + e)\rho_w / (1 + e) = \rho_s$$

Where G_s : Specific Gravity of Soil = 2.7

e : Void Ratio

ρ_w : Density of Water = 1.0

25 ρ_s : Density of Slurry = 1.07~1.14

$$e = (G_s \rho_w - \rho_s) / (\rho_s - \rho_w)$$

The calculation of the soil weight is given according to the following equation:

30

$$V1 = m / G_{spw}, V2 = eV1 = em / G_{spw}$$

$$V1 + V2 = V$$

$$m = VG_{spw} / (1 + e)$$

Where V : Slurry Volume

5 G_s : Specific Gravity of Soil = 2.7

e : Void Ratio

ρ_w : Density of Water = 1.0

10 The total volume is calculated from the sum total of the cement volume, the stabiliser volume, the sodium silicate volume, the weight (or volume) of the water, the ratio of the weight of the soil to the specific gravity of the soil and the weight of the Marine Clay, less the actual weight of the soil. The slurry volume is calculated as the total volume less the cement volume, the stabiliser volume and the sodium silicate volume.

15 Of course, the precise properties of marine clays will vary from geographical area to geographical area. However, the Applicant considers that most and perhaps all marine clays will be suitable for use in the techniques disclosed herein. However, the properties of two exemplary marine clays, both of which are found in Singapore, are given in Table 3 below. These are generally described in Chapter 3 (at page 62) of the paper entitled "Compressibility and undrained behaviour of natural Singapore marine clay: Effect of soil structure" by Low Hang Eng, a Thesis for a Master of Engineering degree conferred by the National University of Singapore (and found at <http://scholarbank.nus.edu.sg/handle/10635/14386>), but have the following

20 properties in summary.

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<u>Geotechnical Properties</u>	<u>Upper Marine Clay</u>	<u>Lower Marine Clay</u>
Liquid limit (percent)	87±9	75±7
Plastic limit (percent)	31±4	29±3
Plasticity index (percent)	56±8	46±6
Liquidity index	0.65-1	0.6

<u>Geotechnical Properties</u>	<u>Upper Marine Clay</u>	<u>Lower Marine Clay</u>
Activity	1	1
S_u/σ_{vo}'	0.18-0.41	0.25-0.41
Sensitivity	1.5-6	3-5
Effective shear strength parameter c' (kN/m ²)	3	7
ϕ'	21.5°	21.5°
Yield stress ratio (YSR)	1-1.5	1-1.5
Compression Index, C_c	0.7-1.3	0.45-0.95
Recompression Index, C_r	0.083-0.3 C_c	0.083-0.3 C_c
Coefficient of consolidation for vertical flow, c_v (m ² /year)	0.5-5.0	0.5-2.0
Coefficient of consolidation for horizontal flow, c_h (m ² /year)	2-3 c_v	2-3 c_v
Coefficient of permeability, $k_v \times 10^{-8}$ (cm/sec)	1-20	
E_u/S_u	170-300	170-300
K_o	0.52-0.72	0.52-0.72

TABLE 3

Of course, the backfill grouts as disclosed herein may also contain other additive
5 agents, such as foaming agents.

The stabiliser has a retardation effect to prevent hardening of the A-liquid prior to it
being mixed to shot. With the amount of stabiliser given above, this may achieve a
desired result of providing a retardation time of 24 hours or more.

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The backfill grouts disclosed herein may provide an A-liquid having a binding agent
providing acceptable performance for the avoidance of material separation. Thus, in
the case of resistance to material separation being too low, the materials will
separate by breezing, also running the risk of choking inside the supply pipes.

15 Conversely, where the material separation resistance is too high, the conveying

resistance of the A-liquid is correspondingly increased, perhaps to unacceptable levels. Thus, the situations may be avoided by the provision of an A-liquid and backfill grout materials as described above.

- 5 The backfill grouts disclosed herein may be used in, for example, backfilling in tunnel boring machine excavation operations.

The Applicant has also found that other types of excavated clay may also be used in the A-liquid in the alternative to marine clay. For instance, sufficient amount of silt
10 and clay may be contained in the following general excavated soils:

- Old Alluvium (using clay contents)
- Granite Residual (using clay contents)
- Jurong Formation Residual (using clay contents)

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When using particles – gravel, sand and/or clay – from these general excavated soils, these may also be used as an alternative to bentonite. Thus, the disclosures of this application extend to the provision of a backfill grout A-liquid having a binding agent comprising excavated clay. Further, the disclosures of this application extend to a
20 backfill grout comprising such an A-liquid. Further, the disclosures of this application extend to a method of preparing an A-liquid for backfill grout, the method comprising including excavated clay in the A-liquid as a binding agent. The method also extends to the preparation of a backfill grout comprising such an A-liquid. Yet further, the method extends to use of excavated clay as a binding agent in an A-
25 liquid for a backfill grout.

It will be appreciated that the invention has been described by way of example only. Various modifications may be made to the techniques described herein without departing from the spirit and scope of the appended claims.

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CLAIMS

1. Backfill grout A-liquid having a binding agent comprising marine clay.
- 5 2. The backfill grout A-liquid of claim 1, wherein the binding agent does not comprise bentonite.
3. The backfill grout A-liquid of claim 1 or claim 2, formed with the binding agent comprising a slurry having the marine clay, the slurry having a specific gravity
10 of between 1.01 and 1.23 and a Marsh funnel viscosity of between 19 seconds and 40 seconds, wherein the slurry is such that an increase in the specific gravity above 1.01 results in a corresponding increase in the Marsh funnel viscosity above 19 seconds.
- 15 4. The backfill grout A-liquid of claim 3, wherein the slurry has a specific gravity of between 1.07 and 1.14 and a Marsh funnel viscosity of between 20 seconds and 22 seconds.
5. The backfill grout A-liquid of any preceding claim, wherein the marine clay
20 comprises particles of not more than 0.063mm in diameter.
6. A backfill grout comprising the A-liquid of any of claims 1 to 5.
7. A method of preparing an A-liquid for backfill grout, the method comprising
25 including marine clay in the A-liquid as a binding agent.
8. The method of claim 7, wherein the method comprises preparing an A-liquid not having bentonite.

9. The method of claim 7 or claim 8, the method comprising preparing the A-liquid where the binding agent comprises a slurry having the marine clay, the slurry having a specific gravity of between 1.01 and 1.23 and a Marsh funnel viscosity of between 19 seconds and 40 seconds, wherein the slurry is such that an increase in the specific gravity above 1.01 results in a corresponding increase in the Marsh funnel viscosity above 19 seconds.
10. The method of claim 9, the method comprising forming the slurry with a specific gravity of between 1.07 and 1.14 and a Marsh funnel viscosity of between 20 seconds and 22 seconds.
11. The method of any of claims 7 to 10, the method comprising forming the slurry with marine clay comprising particles of not more than 0.063 mm in diameter.
12. A method of preparing a backfill grout, the method comprising using the method of any of claims 7 to 11 to prepare an A-liquid for the backfill grout.
13. Use of marine clay as a binding agent in an A-liquid for a backfill grout.