TECHNICAL SHEET

Designing effective sand and mortar mixes for Micro Concrete Roof Tiles (MCR)

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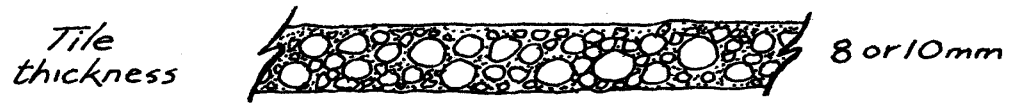
Designing sand compositions for mcr tiles.

To produce strong tiles, it is important to use clean sand with the correct ratio of **fine grains** (less than 1mm), **medium sized grains** (1mm to 2½mm) and **large grains** (2½mm to 5½ for 8mm - or 7 for 10mm).

Tile thickness can be **8mm** or **10mm** - no sand grains should exceed **⅔ the tile thickness**.

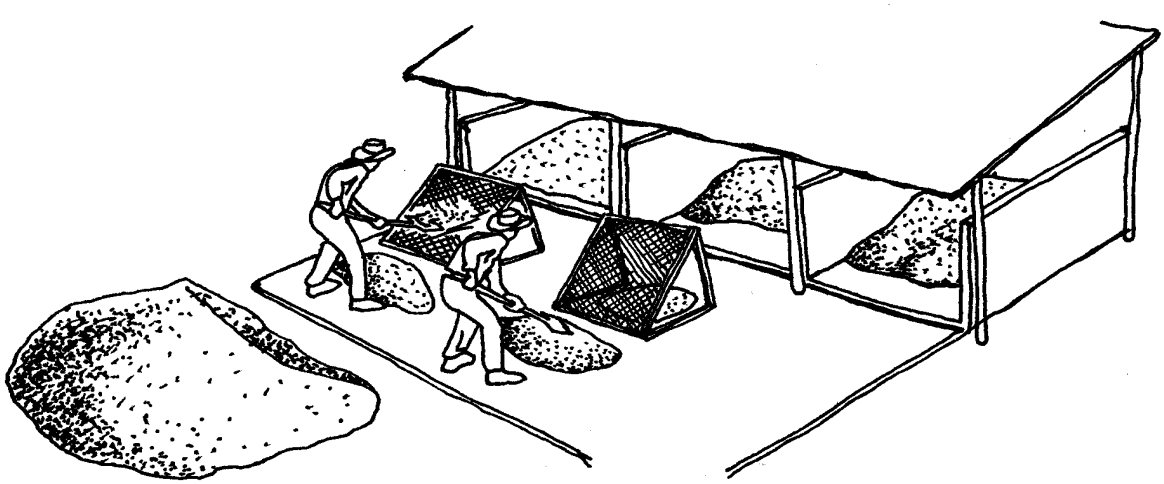
In the **vibrating mortar**, the **medium grains** fill space around the **course grains** … with **fine grains** filling the spaces in between. The closer the fit, the **denser** and stronger the tile.



If there are more **fine particles**, the mortar is easy to work with … but the mix needs more water and cement to cover the surface area of the fine particles … causing more shrinkage and porosity.
- More **course aggregate** uses less cement and water, shrinking less … but can be less workable.

Silicous or volcanic sands are commonly used.
- The sand should be free of organic material, with not more than 4% **clay** and **silt**.
- Round grained sands are better than flat particles.
- River sands used on building sites to mix mortar and cement are suitable.

To avoid wastage, mixing your sand with the ground it lies on and water takeup - it is good practice to store sand on a **concrete surface**. To separate different **grades of sand**, construct **sand bins** by building 1.2m high nib walls, 2 to 3m apart forming divisions between the graded piles of sand.



Sand should be **stored under cover** so that rain and damp do not add too much water to the sand.
- Dry sand can be consistently batched into mortar mixes with measured amounts of water.
- wet sand already has water, so that the water/cement ratio in your mix will have too much water.

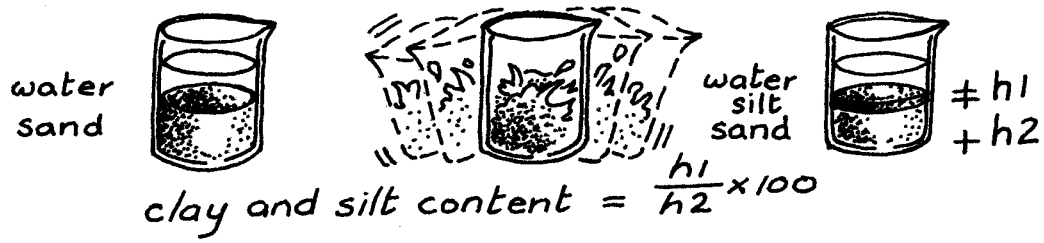
Depending on where you are digging the sand … or where suppliers you buy sand from are getting their sand - you might be able to get a **consistent type of sand** … or each sand order might have a different mix of sand grain sizes. Obtaining a supply of sand of the same appropriate consistency is useful.

Each time you receive a different type of sand for tile-making, you should test it to find out whether you can use it as it is, or whether you have to sieve it into grades and combine the right proportions.

- A ***clay/silt content test*** … finds out what percentage of clay/silt the sand has.
- A ***sand grading test*** … finds out the proportion **of fine, medium** and **course grains** in the sand.

Testing the clay/silt content of your sand.

You need to find out 'what **percentage** of the sand is **clay** or **silt**.
The sand should not contain more than 4% **clay** and **silt**
If there is more than 4% clay and silt, the sand can be 'washed', but this can also wash away fine sand particles, wastes water and makes your sand wet - so better to find an alternative sand source.



1 - Take a **sand sample** as described below and fill one half of a **glass jar** with the **sand**. Add **water** to 50% above the sand level and **shake the jar** strongly for 30 seconds.
- Place the jar on a table for at least one hour to allow the **sediment** to settle and water to clear.

2 - Measure and record the depth of the **clay and silt layer (h1)** and the depth of the **sand layer (h2)**.

3 - Now the calculation h1 ÷ (h1+h2) x 100 will give the percentage of clay and silt in the sand.

► In our example the clay and silt content is 2.7% - This is under 4% and acceptable.

Depth of clay + silt - h1	Depth of sand - h2	H1 ÷ (h1+h2) x 100	Clay + silt content of sand
2mm	75mm	2 ÷ 77 x 100 = 2.6%	2.6%

Grading the sand and finding out its composition.

The sand is offloaded in a pile or into a sand-bin at your workshop.

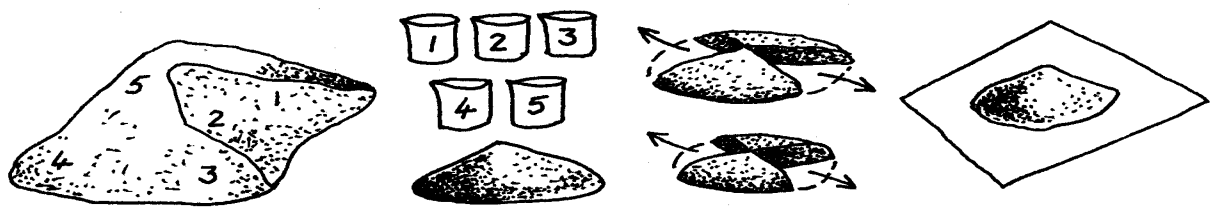
You need to find out - what percentage of the sand is **fine grains** (less than 1mm), what percentage is **medium sized grains** (between 1mm and 2½mm) and what percentage is larger **course grains** (between 2½mm and 5½mm for 8mm tiles or 2½mm and 7mm for 10mm tiles).

One way to do this is to use **three small sieves** (7 or 5½mm mesh - 2½mm mesh - 1mm mesh) in 300mm x 300mm frames - a **one** or **1½ litre measuring jug** calibrated with markings showing volume in millilitres (a clear plastic kitchen litre jug with millilitre markings is ideal). … and a **pocket calculator**.

1 - Take a **sample of sand**

To get a **sample** of the sand that 'represents' the **mix of sand grades** in the whole pile -

Take one litre container-fulls of sand from five different parts of the sandpile (dry load the container and level with one litre gauge, do not compact the sand) … and mix them together thoroughly - form the mixed sand into a round 'pie' of sand on a concrete surface or sheet of thick plastic and divide it into 4 segments - remove and throw away two opposite segments - mix again - form a pie - throw away two opposite segments - then mix again to obtain your sample.
Put the sample of sand onto a sheet of plastic or stiff paper to control the sample and not loose sand.



2 - **Sieve** and **measure** the **volumes** of each **grade of sand** in the **sample**

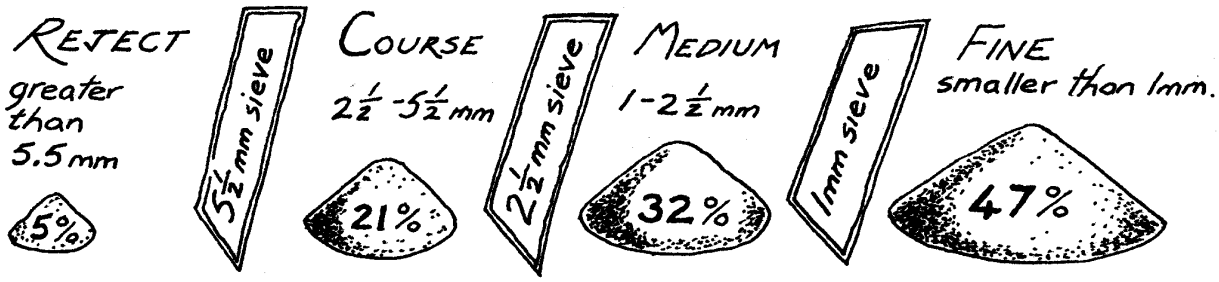
- Pass the sand in your sample through a **5½ or 7mm sieve** onto a sheet of plastic or paper. The grains that remain in the sieve are **bigger than 5½mm** and can't be used in the tile mortar. Pour these into the **measuring jug** and record how many **millilitres** of these grains you have. Empty the jug to form a pile of this sand on another plastic or paper sheet for visual inspection.

- Take the sand that went through the 5½mm sieve and pass it through a **2½mm sieve** - pour the sand that remains in the sieve into the **measuring jug** and write down how many millilitres of **course grained sand** (2½ to 5½/7mm) you have - empty jug into a pile next to the sand greater than 5½mm.

- Take the sand that went through the 2½mm sieve and pass it through a small **1mm sieve** - pour the sand that remains in the sieve into the **measuring jug** and write down how many millilitres of **medium grained sand** (1 to 2½mm) you have - empty into a pile next to the large grained sand.

- Now use the **measuring jug** to measure how many millilitres of **fine grained sand** (smaller than 1mm) that passed through the 1mm sieve remain and write this down - empty the jug next to the medium grained sand.

► In our example –



A - Too big	**B** - Course sand	**C** - Medium sand	**D** - Fine sand	**Total 1**	**Total 2**
Bigger than 5½mm	2½mm to 5½mm	1 to 2½mm	Smaller than 1mm	**B+C+D**	**A+B+C+D**
62 millilitres	250 millilitres	375 millilitres	563 millilitres	1188 ml	1250 ml
(5%)	21%	32%	47%	100%	100%

3 - Work out **sand grade proportions** in **percentages**.

To find out what percentage of your delivered sand is too big to use for mcr tiles (bigger than 5½ or 7mm) - Divide **Total 2** by 100 to find one percent (1250÷100=12.5). Then divide **A** by this one percent to find the percentage of sand that is too big (62ml÷12.5=5%) … or use … $\frac{\text{Total } \mathbf{A}}{\text{Total 2}} \times 100$
► In our example **5% cannot be used** for tile mortar.

To find the percentages of each **grade of sand** in the sand that can be used -
- Divide **Total 1** by 100 to find one percent (1188ml÷100=11.88). Then divide **B** by this one percent to find the percentage of sand that is 2½ - 5½ mm (250ml÷11.88=21%) … or use … $\frac{\text{Total } \mathbf{B}}{\text{Total 1}} \times 100$
► In our example 21**%** of the usable sand is **course**.

► Repeat for **C** and **D** to find these percentages and write them down … $\frac{\text{Total } \mathbf{C}}{\text{Total 1}} \times 100$ … $\frac{\text{Total } \mathbf{D}}{\text{Total 1}} \times 100$

Here the sand is being **measured by volume** in the **measuring jug**.

An alternative method is to measure the sand by **weight** on a **kitchen scale**. As with millilitres the weights are found for each grade of sand, the total weights calculated and percentages calculated.

4 - Do a **visual inspection** of the 4 piles of sand that you have heaped next to each other.

Recommended sand compositions.

Remember … In the **vibrating mortar**, the **medium grains** fill space around the **course grains** … with **fine grains** filling the spaces in between. The closer the fit, the **denser** and stronger the tile.

- If there are more **fine particles**, the mortar is easy to work with … but the mix needs more water and cement to cover the surface area of the fine particles … causing more shrinkage and porosity.
- More **course aggregate** uses less cement and water, shrinking less … but can be less workable.

Sand grade percentages that fall within the ranges shown below are recommended.

Thickness	Maximum size	**Coarse** - 2.5 to 5.5m	**Medium** - 1 to 2.5mm	**Fine** - less than 1mm
8mm tile	5.5mm	30-50%	10 - 55%	15 - 40%
10mm tile	7mm	35 - 55%	15 - 45%	10 - 40%

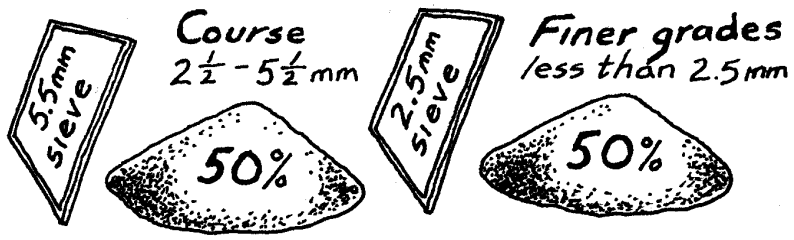
In general practice -

1 - Workshops use a **5½mm sieve** (for 8mm tiles) or a **6½** or **7mm sieve** (for 10mm tiles) to remove everything that is too big to use.

- If the sand you receive has roughly the right proportion of sand particle sizes after being passed through the **5½mm** or **7mm sieve**, it can be used as it is. This means you need only sieve it once.

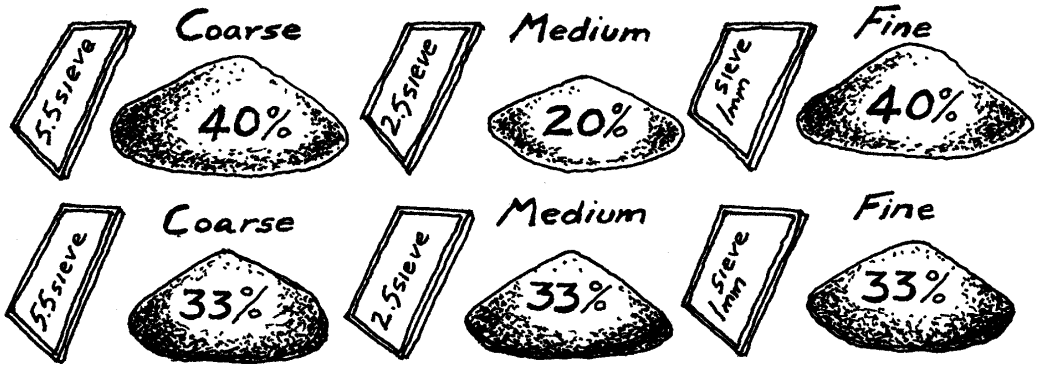
2 - If not, pass the sand through a **2½mm sieve** to separate the **course grains** (2½-5½mm particles).

- Some workshops then make a **50/50 mix** of the **course sand** and **finer grades** that pass through.



3 - For a quality mix, sieve the finer grades obtained in (2) through a **1mm sieve** to separate the **medium** (1-2½mm particles) and **fine** grains (less than 1mm).
Each sand grade is then stored separately for batching into the mortar mix.

- Some producers find a mix of **40% course** + **20% medium** + **40% fine** produces the strongest tiles.
- Some use **equal amounts** of **each grade** …**33% course + 33% medium + 33% fine**



Try different **sand mixes** and make **sample tiles** to check the **workability** of the mortar - break these tiles after 28 days to measure their strengths and see which sand mixes produce the strongest tiles.

Balancing the sand composition

► In our example we had too much fine sand … and too little large grained sand.

To balance the sand - **sieve** the supplied sand through large **5½**, **2½** and **1mm sieves** and store each grade separately. When making a tile mortar mix **batch** and mix **equal amounts** of **fine, medium** and **coarse sand** directly from each graded sand pile ... or batch out and mix sufficient sand for the day.

Finding a consistent supply of sand with the right proportion of grades is useful … if that is not possible … you can get loads of **coarser** or **finer sand** to balance out surpluses of one grade.

If you want to combine two loads of sand to balance your sand composition - you can use the following method to find out what percentage of the one **sand type** to combine with the other **sand type**.

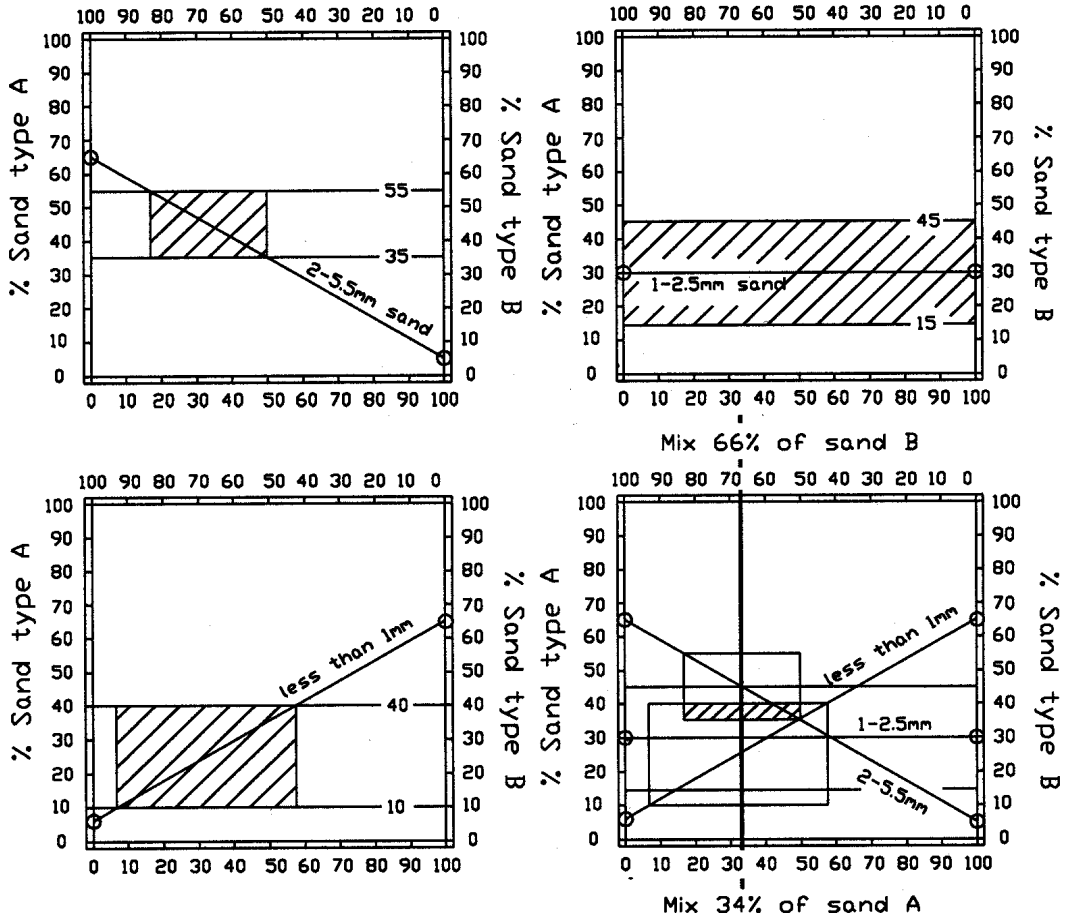
1 - First use the sand grading method to work out what percentages of coarse, medium and fine sand the two sand types have. We are making **10mm tiles**. In our example we found the following -

	Coarse 2½-5½mm	**Medium** 1-2½mm	**Fine** less than 1mm
Sand Type A	65%	30%	3%
Sand Type B	5%	30%	65%
Acceptable variance	35 - 55%	15 - 45%	10 - 40%

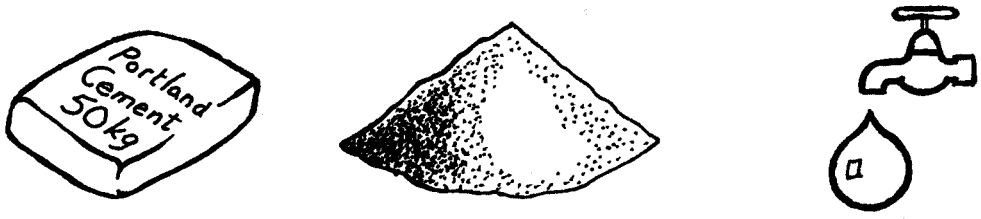
2 - Plot the **percentages** of the two **sand types** … and the **acceptable variance** for each grade on a graph, hatching the area of overlap as shown below.

3 - Overlay the three graphs to find the area of common overlap … and draw a **vertical line** through the **centre** of this **overlap**. Percentages on the **top** and **bottom scales** that this vertical line passes through, give you the percentages of each sand to mix for combining the two sands.

► In our example we combine **34%** of sand **type A** … with **66%** of sand **type B**.



Designing the mcr tile mortar mix.



Tile mortar is made by mixing cement, sand and water together.

The **cement** and the **water** begin a **chemical reaction** when mixed together, slowly hardening in all the spaces between the **sand grains** to bind them together. This ongoing chemical reaction as the tiles are 'cured' goes on for years, but 28 days is taken as sufficient time to consider the tiles ready for use.

Slowing down the chemical reaction makes the **micro concrete** stronger … we slow down the reaction in tile-making … by keeping the tiles sealed between the moulds for 24 hours, 'stewing in their own water vapour' … becoming hard enough to demould - then placing them under water in curing tanks for 7 days - before air drying in shade for 20 days.

- If the **mortar is too wet**, the vaporising 'surplus' water (not absorbed in the chemical reaction) leaves hollow pores as the tiles 'shrink', which weaken the tiles and make them vulnerable to water penetration. When moulding the tiles, the mortar will 'slump' and not hold its shape.

- If the **mortar is too dry** there might not be enough water to reach all the cement and complete the chemical reaction. The mortar is too 'stiff' to mix effectively and work with easily.

When working with mcr tile mortar …

The **sand** and the **cement** must be **thoroughly pre-mixed** and the **wet mortar** again thoroughly mixed. It is important that the correct **ratios** / **amounts** of **cement**, **water** and **sand** are used in the mortar mix.

If the **mortar** is allowed to stand for too long, tile strength is lost.
- Fresh mortar mixes should be made at least **every hour** … **gauged** to provide sufficient mortar to produce the **number of tiles** being produced in an hour. Use up the mix before stopping work.

It is best to mix mortar on a **concrete surface** or on something that separates the mix from the soil and does not take up water from the mix. In Latin America people form a shallow depression or bowl in a concrete floor to contain the mix and water.

Mortar should be mixed and used under **shade cover** to minimise moisture loss while in use.

If you are adding **oxide** to colour the mix, add 3 to 10% of the **cement weight**.

Water / cement ratios

To work out the amount of each material to use in the tile mortar mix, we use the concept of **water:cement ratio**.

The **water:cement ratio** is the **ratio** of the **volume of water used** (in litres), to the **weight of cement used** (in kilograms) … number of litres of water … or … litres water : kgs cement.
number of kilograms of cement

eg: If you use 3 kilograms of cement with 1½ litres of water … 1.5 litres of water = 1,5l ÷ 3kg = 0.5
you have a water/ cement ratio of 0.5 3 kilograms of cement

one litre of water weighs one kilogram … one cubic litre of water (1000 litres) weighs one ton (1000 kgs)

A water cement ratio of 0.5 means that for every kilogram of cement, you are using half a litre of water.
eg: You would mix 25 litres of water with a 50 kilogram bag of cement.

One kilogram of cement needs a minimum of 360 millilitres of water to make its chemical reaction.
… this gives a water / cement ratio of 0.36

- But 0.36 is too dry to mix effectively … and the mix is too stiff to work with.
- With a cement mixer you can reach mixes with water / cement ratios of 0.4
- Mixing by hand, it is difficult to get water / cement ratios below 0.5
  Practically, most workshops use water / cement ratios from 0.5 to 0.65

Working out the best mortar mix for your sand.

Different sand mixes take up water slightly differently … sand with a greater proportion of fine sand needs more water to cover the surface area of the sand grains.

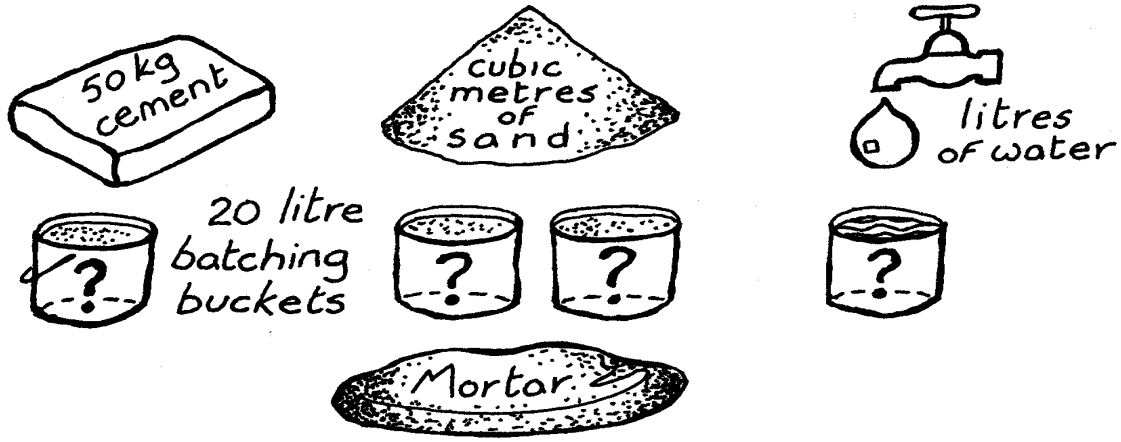
To find out the best mix proportions for your sand you need to prepare a **sample mix**.

To prepare a **sample mix** start by choosing an appropriate **water:cement ratio** such as **0.5**
- to get a **0.5 water:cement ratio** mix half a litre of water with every kilogram of cement.

Cement : sand mixing ratios for tilemaking mortar are normally between **1:2** and **1:3½** by volume
- so start with a 1:2 cement:sand ratio by adding twice as many litres of **sand** (by volume) as the number of litres **cement** you mixed with the water … mix thoroughly … explore workability
- then add **measured amounts** (in litres) of extra sand to get the right workability.

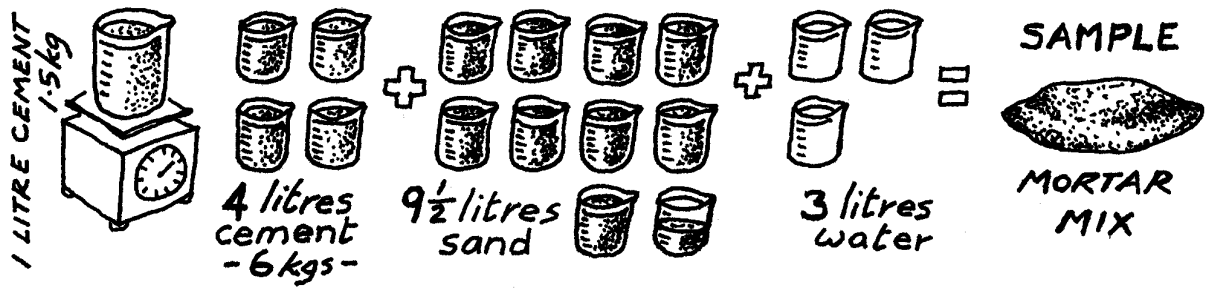
From the **measured volumes** of materials used to make the **sample mix**, you can work out how many **batching buckets** of each material should used to make **working mortar mixes**.

You need to find out … **how much cement** … **how much sand** …and … **how much water** you must combine to make the right quality of **mortar mix**.



Making a sample mortar mix

… you need… a **scale** measuring up to 3kg marked in grams and kilograms and a **1 litre** or **1.5 litre measuring jug** calibrated with markings showing volume in litres and millilitres.



1 - **Weigh one litre of cement -** First weigh the empty measuring jug on the **scale**.
- Fill the jug with **dry cement powder** to the one litre mark, avoiding cement compaction.
- Weigh the **jug plus cement** on the scale and record the weight in **kilograms**.
- Subtract the weight of the jug to find the **weight of one litre of cement** in **kilograms** (1.2-1.52kg)

(one kilogram = 1000 grams … to change grams to kilograms divide the number of grams by 1000)

2 - Now make a dry **1:2 cement / sand mix**, adding **two litres of sand** for every **one litre of cement**.
- Use **dry sand** and **mix** the sand and cement together thoroughly.
- The mortar for tilemaking should have a **cement:sand ratio** by volume of between 1:2 and 1:3½

► In our example we used 4 litres of cement with 8 litres of sand …
… so that we would have a mix big enough to make 7 test tiles.

3 - **Add half a litre of water** for every **one kilogram of cement** -
(Divide the number of **kgs of cement** by 2 to find the number of **litres of water** to add to the mixture)
- Add the water bit by bit, mixing thoroughly.
- using half a litre of water for each kilogram of cement gives us a water : cement ratio of 0.5.

(one litre = 1000 millilitres … to change millilitres to litres divide the number of millilitres by 1000)
(One litre of water weighs one kilogram)

► In our example, one litre of cement weighed 1.5kg. We used 4 litres of cement in our sample mix -
… 4 x 1.5kg = 6kg. If the cement weighs 6 kilograms (6kg cement÷2 = 3) so we used 3 litres of water.

4 - Examine the mixture and **squeeze a bit of mortar in your hand**, forming a fist around the wet mortar. If water trickles out between your fingers, the mix is too wet - a few small drops of liquid should appear.

5 - Using a **1:2** by volume **cement:sand mixture** will probably give you a mix that is too wet … cement:sand ratios can range between 1:2 and 1:3½ … so add a **measured amount** of **additional sand**, bit by bit to get the right consistency. Record the amount you add.

► In our example the mix was too wet so we added **1½ litres of extra sand** to get the mortar workable.
- This kept the water cement ratio at 0.5 - and pushed the cement:sand ratio from 1:2 to 1:2,4.

	Cement	Sand	Water	Water/cem ratio
Initial sample mix	4 litres - 6.08kg	8 litres	3 litres	0.5
Amount added	-	1½ litres	-	0.5
Total	4 litres	9½ litres	3 litres	0.5
Batching ratio	20 litres - 1 bucket	47.5 litres - 2⅓ buckets	15 litres	0.5

Making mortar mixes with a higher water cement ratio such as 0.6 reduces mortar strength a bit … but allows the mix to take up more sand. This means you use a bit less of the costly cement in each tile … which reduces tile production costs … but exceeding 0.65 compromises tile strength significantly.

6 - Now use the mortar to **make some sample tiles**, observing the mortar's **workability** and **slump**.
- If you observe water 'pooling' on the surface of the mortar when spreading the mix during vibration the mix is a bit too wet - if the mortar is too stiff to spread effectively, the mix is too dry.
- If the mortar feels too **wet** or **stiff** - make another **sample mix**, adding additional recorded amounts of **sand** or **water** … and again make and test **sample tiles**.

7 - Demould the **sample tiles** after **24 hours**,
- Examine the **ends of the tiles** after demoulding and striking off the edges. The **thickness** of the tile should be uniform. If the tile is thicker in the ridges, it means the mortar was too wet and has 'slumped' into the hollows of the mold. This can effect the interlocking 'fit' of the tiles.
- if the tile shows **shrinkage cracks** and '**pores**' (small cavities where evaporating water escapes) the mix was too wet … or the molds are not sealing effectively against each other.

8 - Break 3 sample tiles after 24 hours to measure their strength.
- **8mm tiles** should resist a minimum standard of **15kg** at this stage of curing ... (strong tiles 20-25kg)
- **10mm tiles** should resist a minimum standard of **20kg** at this stage of curing ... (strong tiles 25-35kg)

After 28 days of curing break 3 more sample tiles, recording average strength -
- **8mm tiles** should resist a minimum of **50kg**, preferably **80kg**… (strong tiles 85 - 110kg)
- **10mm tiles** should resist a minimum of **80kg**, preferably **100kg**… (strong tiles 110 - 140kg)

For comparative strength with other concrete roof tiles the South African Bureau of Standards (**SABS**) requires **100kg** … so commercial producers should consider producing 10mm tiles.
- To comfortably walk on the roof, tile strengths of 90 - 120kg are better, to carry 60 - 80kg people.

- Tile strengths increase significantly over the first year, particularly with frequent exposure to water. Break some test tiles **after 6 months** and **one year** of lying on a demonstration tile rack in the yard to find their strengths and compare with the average strength of the 3 tiles from the same test batch that you broke after 28 days.

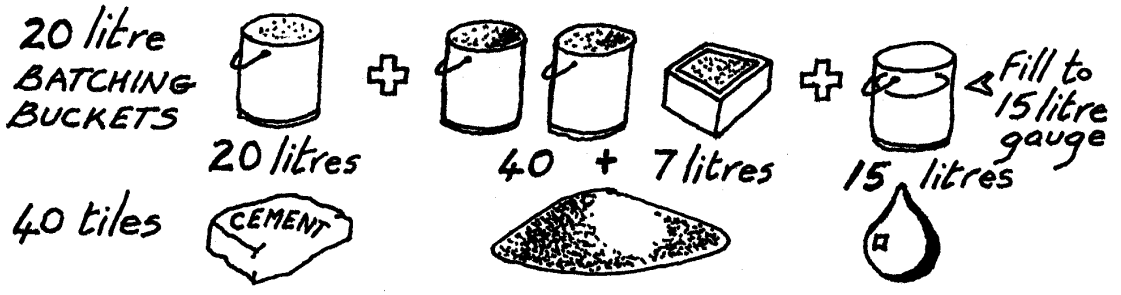
Tile production Workshops should have basic **quality control equipment** such as **sieves**, a **scale**, a **litre measuring jug**, a **calculater** … and a **'tilebreaker'** to measure tile strength.

- A simple **'tilebreaker'** that uses a tubular steel frame and lever arm with a gradated bucket, gradually filled with water … can be made up to measure the breaking strength of the roof tiles. (See Flexion Test equipment).
- Having this equipment enables tile producers to establish which sand and mortar mixes produce the strongest tiles, conduct ongoing monitoring of tile strength … and demonstrate tile strength to customers.

9 - When mixing the mortar for tile-making the materials can be **batched** into the mixture using **twenty litre batching buckets**, so that the mix always has the same proportion of materials.

► In our example … If one machine is working, a tile-maker should produce 30 - 40 tiles per hour. One 20 litre bucket of cement can make 36 tiles - so we base our batching ratio on one bucket of cement.
- In our sample mix, we used 4 litres of cement. To get a 20 litre bucketful we need to multiply our sample volumes by 5 (4 litres of cement x 5 = 20 litres).
- 9½ litres of sand x 5 = 47½ litres or two 20 litre buckets and a scoop carrying 7½ litres of sand.
- 3 litres of water x 5 = 15 litres - to use a 20l batching bucket to measure the water, fill the bucket with 15 litres of water using a measuring jug. Then mark the waterline in the bucket so that the correct volume of water for the mix can be gauged by filling the bucket up to the mark.

Draw a diagram of the **batching ratio** by volume and put it on the wall next to the mixing area.

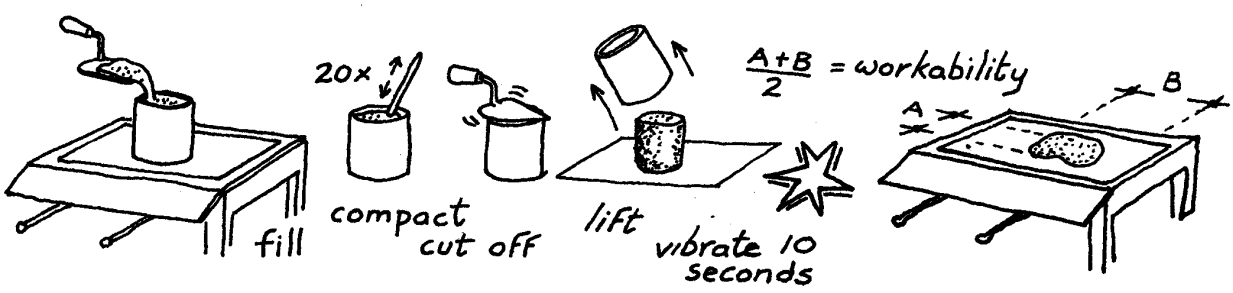


The Workability test - monitoring mortar consistency.

It is not necessary to repeat the **mortar design process** too often - one would check the mortar design if the **mix of sand** you are using **changes,** or if **wet** and **humid conditions** cause your sand to take up a lot of water in storage.

To check the **consistency** of the **mortar** on a daily basis, use a simple test called the **workability test**.

To do this you need a **round tube open on both ends** … a cool-drink can can work, with the top and bottom removed … or ideally a 47mm long steel pipe section with a 67mm diameter … and a **ruler**.



1 - Place the **tube** on the **vibrating table** and **fill with mortar, compacting** 20 times with a small stick. Cut the mortar flush with the top. Now lift off the tube, leaving the mortar cone on the table

2 - Look at a watch and **vibrate** the mortar for 10 seconds.

3 - Measure the width of the **mortar spread** in two directions and record the average spread.

Each mortar mix with the same **workability**, should have the same '**spread**'. So you can repeat this exercise from time to time and compare with your **'control width of spread'** …as a way to check that your mortar mixes are remaining consistent.