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Publisher's version / Version de l'éditeur:

Indian Concrete Journal, 70, 3, pp. 133-138, 1996-03-01

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NRCC-40084

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March 1996

A version of this document is published in / Une version de ce document se trouve dans:
Indian Concrete Journal, 70, (3), pp. 133-138, March 01, 1996

Self-levelling cement-based underlayments

Noel P. Mailvaganam

Self-levelling underlayments are primarily used to provide a smooth or level floor surface before floor coverings are applied. They reduce sound and heat transmission as well as provide additional fire resistance. Most products are applied over old or new floors constructed of cast-in-situ concrete, precast concrete or wood and are being increasingly used to repair floors that have deteriorated, sagged, scaled, or wornout. The materials are easy to use, eliminate troweling and can take foot traffic in 4 to 6 hours at a temperature in the range of 15-32°C (60°- 90°F)[1,2]. Prepackaged proprietary materials when mixed with water, produce self-levelling slurry-like-mixes that can be placed either by pumping, squeegee, or spread by trowel, Fig 1. Although termed self-levelling, most products have to be spread with some tool and some products have to be floated lightly, especially those containing aggregates.

This paper discusses the technology relating to self-levelling characteristics, installation and quality control of cement based underlayments. It also presents a comparison to gypsum-based systems which are also used for similar purposes.

Technology

Flow and self-levelling characteristics are governed by the rheological behaviour of the slurry-like materials produced when the solid components of underlayment products are mixed with water. Most liquids we are familiar with --- water and alcohol for example behave as Newtonian fluids where the relationship between shear stress and rate of shear is linear, the slope of the line being the reciprocal of the viscosity, *Fig* 2(a). Cement and gypsum slurries however, show non-Newtonian behaviour because these are fluids containing large molecules, high concentrations of dissolved solids, or quantities of suspended solids and are said to behave like Bingham fluids. Such fluids are characterised by a finite yield stress which must be exceeded before flow is initiated. The relationship between shear stress and rate of shear is also linear and is related by the plastic viscosity μ, *Fig* 2(b)[3,4].

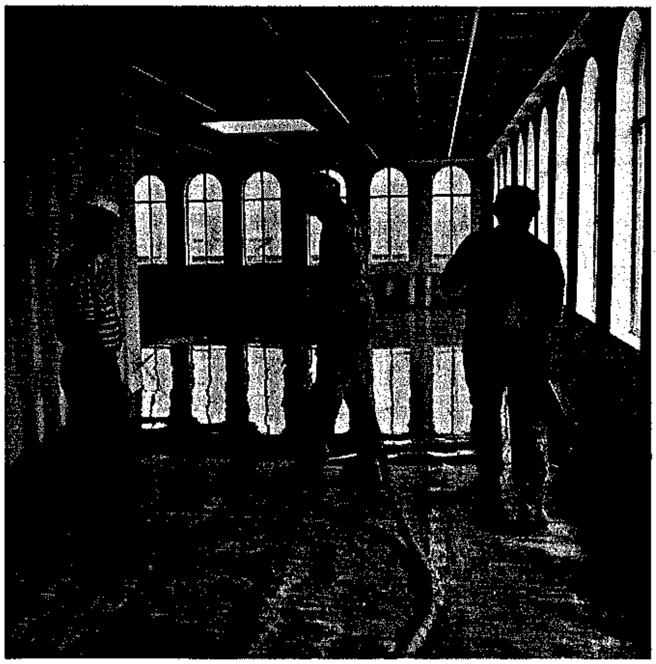

Fig 1 Placing of the underlayment

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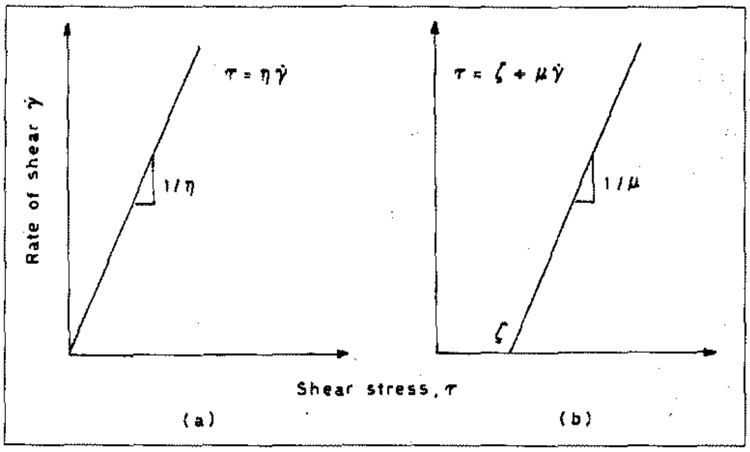

Fig 2 *(a)* **and** *(b)* **Rheological behaviour**

At the low water/cement ratios required to ensure proper suspension of the solids, most self-levelling compositions are characterised by a yield stress and thixotropic behaviour[5], *Fig* 3. Concentric cylinder viscometer tests done on underlayment slurries indicate that they can be considered Bingham fluids, which give yield stresses ranging from 1.6-1.9 N/m^2 and a plastic viscosity of 0.0006-0.0010 N/m^2 [2,5]. To obtain self-levelling properties, the yield stress has to be reduced and this is achieved by the selection and combination of suitable mix ingredients at optimum levels.

Commercially available products are factory pre-blended mixtures of sand, cement and admixtures (superplasticisers, polymer latex and gelling agents) which are included to give specific properties[1,5,6]. For example the addition of a superplasticising admixture results in the reduction of the yield stress and a simultaneous decrease in the thixotropy of the mix. The amount and type of the finest fraction of the aggregate has a significant influence on the stability and flowability of these mortar mixtures -- the finer the fraction, the higher the yield stress, *Fig* 4. Minor variation from optimum grain size distribution however, produces a small effect[5]. Often the finest fraction (0.25 mm) is replaced by fly ash or pulverised blast furnace slag to reduce the susceptibility to segregation.

The pivotal role that a superplasticiser plays in the formulation of self-levelling underlayments is due to the dramatic effects it produces on flow behaviour. Such an effect is believed to be derived by the absorption of the admixture on the surface of cement grains and thereby providing surfaces of a similar or zero charge which are mutually repulsive. They thus fully disperse cement particles, *Fig* 5, freeing more water for lubrication and reducing interparticle attraction. Both yield stress and plastic viscosity are decreased and the decrease is greater for yield stress; it may be completely eliminated if sufficient admixture is added so that Newtonian behaviour is observed, *Fig* 6[3,7].

Although desired properties such as high flow, early strength development and good abrasion can be achieved with a high superplasticiser dosage, there has to be a correct match of the dosage with other ingredients to prevent segregation of the mix in the plastic state[6,8]. The optimum dosage required is dependent on the type of superplasticiser and the amount of cementitious material (type 1, fly ash or blast furnace slag) present in the mixture.

Most superplasticisers are based on either melamine formaldehyde sulfonate (MFS) or naphthalene formaldehyde sulfonate (NFS) which react differently with the various types of cements, *Fig* 7[6]. Thus the type of superplasticiser used in the mixture may influence the flowability of the product at different temperatures. For a given dosage, coarsely ground cements with low C_3A contents (less than 6 percent) produce higher flowability than more finely ground cements with higher C_3A (greater than 8 percent) contents. Similarly, a mixture of cementitious material (type 1 and blast furnace slag) require a lower dosage of the superplasticiser to produce the desired flowability than a mixture containing solely type 1 cement[5,7].

The properties of the finished product are also governed by the type of mixer, mixing time, mixer load and type of pump used. Increasing the vigour of mechanical mixing will lower

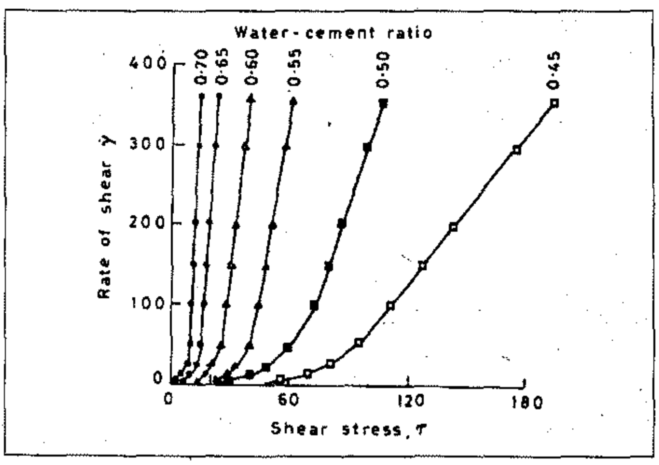

Fig 3 Effect of water/cement ratio on flow behaviour

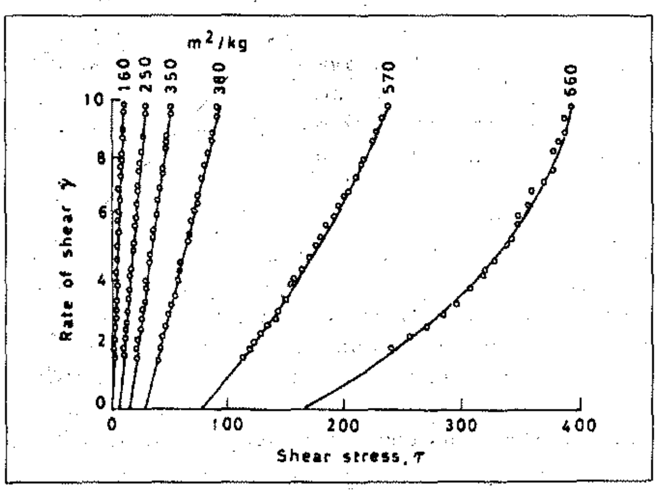

Fig 4 Effect of fine fraction on flow

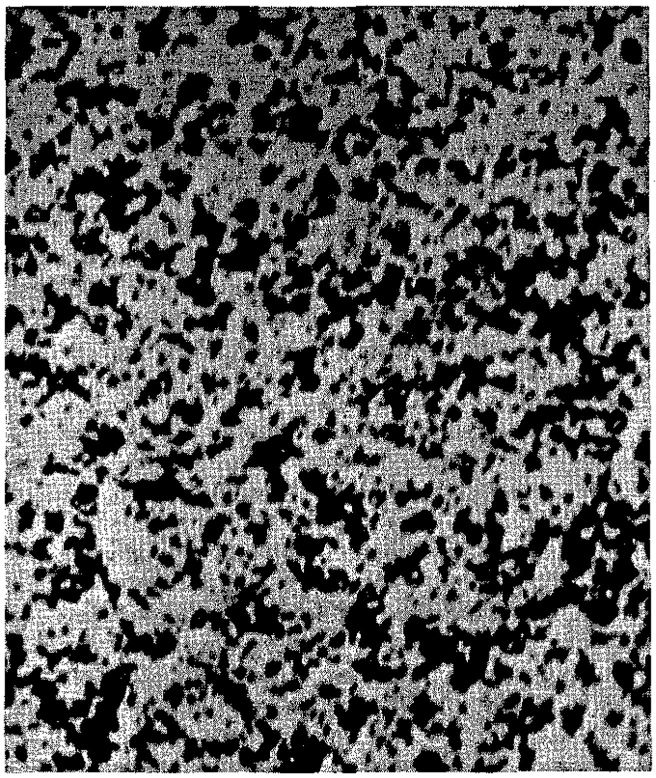

Fig 5 Dispersion of the cement grains by a superplasticising admixture

the yield stress and a wide variation in yield stress and viscosity can be obtained with different mixing procedures, *Fig* 8(a)[3,9,10]. Mixers which produce medium intensity mixing such as pan mixers, give more effective mixing in a shorter time than free fall mixers[7]. The optimum mixing time can range from 3-5 minutes; prolonged mixing may cause rapid decrease in flowability, *Fig* 8(b). With some mixers high loads produce poor mixing due to the inability to disperse the high fines content in water, hence segregation results. Since most self-levelling products are placed by pumping, it is important to use the correct type of pump. Spindle drag pumps connected to the mixer give better results than the piston type which produces relatively high stiffening of the wet mixture[2,10,11].

Types of underlayment

Most self-levelling underlayments are either cement or gypsum plaster based. The two types differ in their installation requirements, minimum and maximum thickness which can be applied, certain properties such as water and fire resistance, rate of curing and costs. Type of floor finish and materials specified therefore, will depend on the nature of operations that will be carried out in the particular location.

Cement based materials are easy to install, when the manufacturer's instructions are diligently followed. Gypsum based underlayments on the other hand must be installed by the manufacturer's approved applicator[1,2]. Since gypsum based products are usually installed thicker than cement based underlayments, the latter materials are more often used in situations where thin layers are required. Minimum thickness for gypsum-based products are usually 10-12.7 mm (3/8-1/2") over concrete and 20 mm (3/4") cover wood. Portland cement-based products are usually installed at 23.18-10 mm (1/8-3/8") over concrete and at least 1/4" over wood[1,9,10]. Gypsum underlayments generally cost less to install than portland cement underlayments, especially when thick layers are applied[1,2].

Portland cement underlayments are water-resistant, whereas gypsum products are not recommended for on--or below grade applications, unless the area is well drained. Portland cement underlayments are generally stronger than gypsum underlayments and are therefore used more for commercial applications where heavier loads are more common. *Fig* 9 shows the crumbling of a weak underlayment subjected to foot traffic.

Gypsum underlayments set faster than portland cement underlayments, permitting foot traffic sooner and the floor can be open to other construction activity. Gypsum products must be cured for at least five days prior to the installation floor coverings whereas for portland cement products they can often be installed within one or two days. Gypsum products are less likely to crack, except for rare hairline cracking. Instead of shrinking and cracking when they are dry, gypsum products expand slightly[1,2]. Thus they can be installed without joints in a continuous pour. Most manufacturers of portland cement underlayments recommend extending the existing floor joints up through the underlayment.

Properties

Self levelling underlayments are formulated for minimal shrinkage, rapid strength gain and flowability without segregation. However, these and other properties can be adversely affected by excessive amounts of water. Too much water will cause dusting, low strength and shrinkage cracks. The materials weigh from 100-120 pcf, produce 28 day compressive strengths in the range of 10.35-38 N/mm^2 (1500-5500 psi), are pumpable and able to level off after minor screeding and be feather edged if necessary[1-10,11]. Depending on the product,

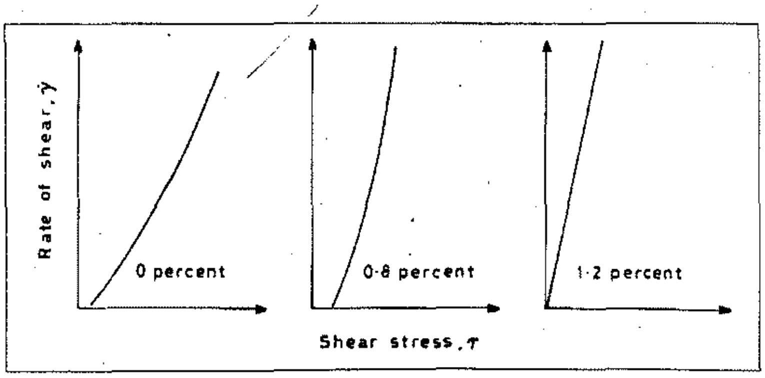

Fig 6 Effect of superplasticiser dosage on flow behaviour

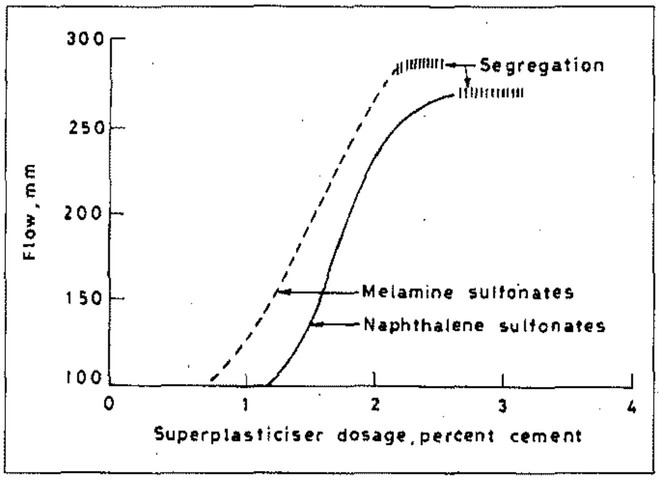

Fig 7 Effect of superplasticiser type on flow behaviour

they can be walked on in 2-4 hours and a floor covering applied in 2-7 days or more after placement[10-11]. *Table* 1 presents properties of some of the products available in the market.

Quality control

Quality of the product is monitored primarily by *(i)* a flowability at stipulated water contents and *(ii)* strength development. Flowability may be measured by an empirical workability test such as the flow trough shown in Fig 10[12]. A stopper at point A is removed to allow 3 litres of the slurry-like mortar to flow along the smooth horizontal steel trough. The distances the mortar flows in 30 seconds is recorded.

Installation

Installation of self-levelling underlayments involves the following steps :

- *(i)* preparation and priming the subfloor
- *(ii)* mixing of the drymix materials with water
- *(iii)* placing (by pump or other manual means) and spreading of the wet slurry and letting it to level
- *(iv)* setting and curing of the underlayment prior to allowing foot traffic
- *(v)* curing of the underlayment to a dry condition (to the manufacturer's stipulated moisture content) before the laying of floor coverings.

Surface preparation

Since cement-based self-levelling products contain high cement contents, they are placed at nearly fluid consistencies over large areas and subject to conditions where high rate of evaporation can occur, there is a high potential for the underlayment to debond. Therefore, it is crucial that the substrate surface be properly prepared to ensure firm bonding of the underlayment. The concrete base does not have to be level, but must be free of dirt and loose dust, grease and oily substances, curing compounds and other matter which will inhibit the formation of a good bond between the base and mortar topping.

Spalled areas and large cracks on concrete subfloors should be patched with repair mortar while neat epoxy liquid can be used to repair the smaller cracks. On wood subfloor, plywood must be nailed down firmly and weak or delaminated plywood removed. Shotblasting and vacuuming may also be required to remove laitance from concrete subfloors[1,2,10].

The sub-floor absorbs water from the underlayment and reduces working time. This should be prevented by coating the concrete or wood base with a primer / sealer after cleaning. The primer which usually consists of a 20 percent solid latex emulsion is applied by squeegee or push broom on to the clean sub-floor. It seals the pores and microcracks of the concrete and wood sub-floor and insures a good bond. To prevent absorption of water from gypsum based wallboards or columns or other absorbent materials, the absorbent medium should be covered with plastic or thin wood strips to the anticipated thickness of the underlayment.

Some portland cement underlayments require special subfloor preparations when they are placed over wood. The preparation may include stapling a metal lath mesh to the floor to provide a mechanical bond with the underlayment. The mesh also prevents cracking of the underlayment by distributing loads from movement over a great area[1,9].

Most products are factory preblended mixtures which only require the addition of the recommended amount of water to achieve the fluid like composition. It is important to adhere to the manufacturer's recommended water content as excess water reduces strength, causes shrinkage and results in surface dusting, which inhibits the bonding of floor coverings. Mixing operations should comply with the manufacturer's recommendations viz. mixer type and period of mixing. This will avoid potential problems such as segregation (due to poor mixing) or a rapid decrease in flowability (due to prolonged

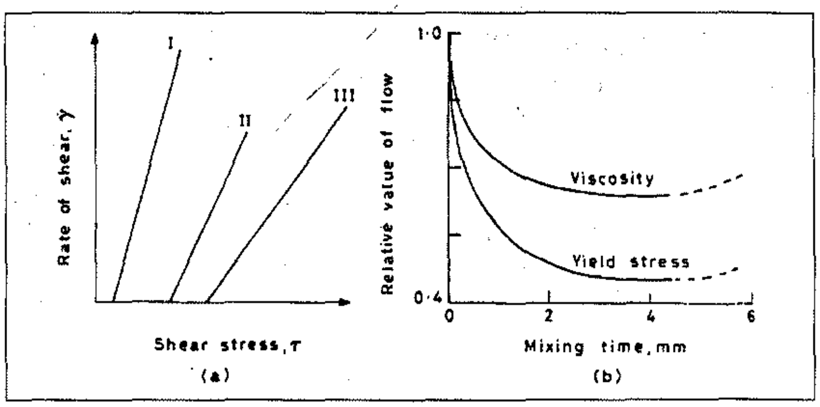

Fig 8 Effect of mixing on rheology *(a)* **Different types of mixing** *(b)* **Effects due to prolonged mechanical mixing**

Table 1 : Descriptions of a few self-levelling underlayment products[2]

Material properties	*Portland cement-based products*						*Gypsum-based products*	
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
Compressive strength, kg/cm^2								
1 day	-	-	184.9	91.39	175.76	-	-	-
28 days	210.9	253.1	288.2	239.04	267.16	372.62	133.5 to 210.9	70.307 to 210.9
Working time, minutes	20	10	10	20	20	10	-	-
Walk on, hours	24 to 48	3	3 to 4	3 to 4	2 to 4	3	$1^1/_2$	$1^1/_2$
Place floor coverings, days	7 to 14	2 to 3	16 hours	1	2[e]	2[e]	5 to 7	5 to 7
Thickness range, mm*	0 to 15.9	0 to 9.5	0 to 38	0 to 12.7	6.35 to 38	6.35 to 38	9.5 to 76.2	9.5 min. (concrete) 19.05 min. (wood)
Extended with aggregates	No[a]	Yes[c]	Yes[c]	Yes[b]	No[a]	Yes[c]	Always	Always
Maximum extended thickness, mm	-	12.7	127	101.6	-	127	-	-
Also used as wear surface	No	No	No	No	Yes	Yes	No	No

* Most products can be feather-edged, if necessary

(a) Already contains graded silica aggregates *(b)* Manufacturer recommends adding 6.8 kg of 3.17 mm sand to each 22.68 kg bag *(c)* Manufacturer recommends adding 3.17 to 6.35 mm fine gravel *(d)* Denotes time when topping can take traffic *(e)* Compressive strength depends on mix design

mixing). Since the mixed material has a limited period during which flowability and self levelling is maintained, it is prudent to mix only enough material that can be applied in 15-20 minutes. The approximate coverage per 25 kg (55 lb) mixed with 0.91 litres (6.5 quarts) of water is --- for 3.18 mm (1/8") thickness 5.58 m^2 (60 sq ft), for 6.3 mm (1/4") thickness 2.79 m^2 (30 sq ft) and for 10 mm (1/2") thickness 1.29 m^2 (15 sq. ft)[1,2,10,13].

Placing

Self-levelling compounds are most often placed by pumping, *Fig* 1. Manual installation by squeegee is sometimes done particularly on the top floors of high rise buildings when there is limitation to the height a given material can be pumped. Most materials are readily pumped, but some products possess rheological properties that are more sensitive to pumpline pressures and respond poorly, causing pumpline blockages. Hence, it is important that the correct consistency (as recommended by the manufacturer) is obtained after mixing so that the rheological properties are compatible with the type of pump used[1,2,9]. It is advisable to carry out pumping trials prior to site work so that the product can be matched with the equipment intended to be used on the job.

Curing

Since underlayments are placed in large expanses, and no curing compounds can be applied to the freshly laid material, they are prone to shrinkage and cracking due to the potential for high evaporation from the surface. Therefore it is important to ensure that the prevailing ambient conditions after placement will produce a more gradual evaporation of mix water. At normal ambient temperatures, 15°-36°C (60°-95°F) most products cure within 4 hours to provide a surface that can be walked on. At lower temperatures, 4-15°C (40°-59°F) it takes an additional 2-6 hours to reach the "walk on" strength[1,2,10].

Precautions

Self-levelling underlayments should not be installed at low temperatures (below 5°C (40° F) for portland cement-based products and below 10°C (50° F) for most gypsum based products). Heat and ventilation may be required for underlayments to dry properly, especially gypsum-based products; these products should not be installed in high humidity. Exposure to direct sun light and drying winds should be prevented to avoid fast surface drying. Normally this is not a problem because materials are designed for interior use only and are enclosed after the building is enclosed.

The high cement and superplasticiser contents in these products result in the rapid hydration of the cement. Thus, high temperatures (27°-31°C, [80-88°F]) can develop when the material is mixed in bulk. Placing of a warm underlayment on a cold substrate (less than 15°C, [60°F]) will result in the debonding of the underlayment as it cures and hardens. Con-

Fig 9 Crumbling of weak underlayment

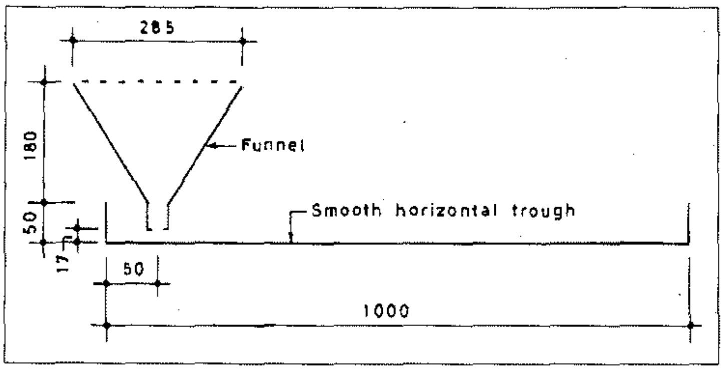

Fig 10 Flow trough used to measure flowability of the mixed material

sequently it is important to ensure that the substrate be maintained at a temperature of 15°C (60°F) prior to placement of the underlayment so that the gap in the temperature differential is significantly reduced.

Not all underlayments are suited to on-grade and below grade sub-floor. Moisture (due to vapour pressure differences; hydrostatic pressure from a high water table; capillary action causing upward migration of moisture) can affect the adhesion of the underlayments to the concrete. Concrete drying time is usually three months, however, this is dependent on slab thickness, heating in the building, time of the year and the manner in which the concrete has been cured[14]. As moisture can interfere with the performance of many underlayments, before placing a floor covering, the moisture condition of the slab should be determined or a test installation of the product to be used should be made. A convenient moisture test that can be done in the field is the plastic sheet test (ASTM D-4263). If no moisture condenses under the sheet after 16 hours the floor is dry enough for most floor coverings.

Prior to material selection and writing of the specification, specifiers must carefully examine interior substrates paying close attention to the factors influencing the bond strength and strength of the finished floor. When installed correctly, self-levelling underlayments dry quickly and bond well to the substrates they are applied to. Their performance will thus be a combination of the best available specification together with the use of correct installation techniques. Therefore, wherever possible, use should be made of a specialist flooring contractor who is skilled in the use of the materials specified.

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