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SELF LEVELING MORTAR: WHY AND HOW?

Ahmed Hassanein
The American University in Cairo, Egypt

Eman Shalaby
The American University in Cairo, Egypt

Omar Amer
The American University in Cairo, Egypt

Reem Ahmed
The American University in Cairo, Egypt

Sherif Orban
The American University in Cairo, Egypt

Amr Fathi
The American University in Cairo, Egypt

Yousef Abu Gharieb
The American University in Cairo, Egypt

Mohamed N. AbouZeid
The American University in Cairo, Egypt

Ezzat H. Fahmy
The American University in Cairo, Egypt

ABSTRACT

Concrete floors can develop faults over time which can cause damage thus hindering smooth transportation, industrial aspects and some residential drawbacks. In addition, flaws and cracks are known to progress into more serious damage with time and use. Self leveling mortar has been used on a relatively limited scale worldwide to allow for more even, higher performance and easy-to-apply flooring. However, there has been little information available with respect to their use and best practices.

The primary focus of this work is to prepare mortar that possesses self-levelling flow characteristics. Hence, several mixtures have been designed using various constituents with moderate 28-day strength of 35 MPa. Chemical and mineral admixtures have been incorporated together with limestone to enhance the flow and cohesiveness as well as improve performance. The results reveal that self-levelling mortar can be successfully produced with comparable properties to ready-to-use market product. These mixtures were evaluated to have both performance and economic merits.

Keywords: Self Levelling, Mortar, Flooring, Cores

1. INTRODUCTION

There are three main uses for the self-leveling concrete. The first use is known as underlayment which is used to smoothen out any surface and correct the irregularities that the concrete could have (Anderberg & Wadso, 2007). This is done prior to the installation of all types of floors. The second usage is to add the self-leveling mortar from the beginning of the project to act as the actual finished floor without the need for a floor covering and this is known as topping. The third use of the self-leveling mortar is as a repair material for damaged concrete in applications such as bridges or roads. Added to that, the self-leveling compounds can be used to provide a smooth and durable new surface for decorative treatments (Klemenc, 2010).

Self-leveling mortar is a ready use mortar, which should be mixed with water before using it directly. Moreover, it is used to create a flat and smooth surface with a compressive strength similar to or higher than the conventional cement mortar, and it is mainly used as an underlayment or as a topping (Klemenc, 2010). For underlayment, it is installed over a subfloor to smooth it or to correct and fix any irregularities on the surface prior to the installations of all floor coverings (Anderberg & Wadso, 2007).

As for toppings, it acts as the actual finished flooring without the need for floor coverings. Nowadays, self-leveling mortar has increased due to the increase in the degree of the flatness and smoothness of floor covering. Self-leveling cement has high flow characteristics in contrast to the conventional cement mortar as shown in Figure 1. It is also characterized by its flow-ability (Lacombe, Beaupré, Pouliot, 1999).

However, as the self-leveling mortar get thicker the flow-ability decreases. Also it can't be applied on vertical surfaces because of its high flow-ability. Self-leveling mortar does not need any vibration or compaction. This material also gets hardened quickly in 20 minutes (Soh & Do, 2002). Consequently, a fast crew is required in order to spread the mortar all over the required area before getting hardened. The only equipment that can be used while spreading the mortar over a huge slab to fasten the process of spreading is an aluminum mob. Another characteristic of self-leveling mortar is the fluidity; it has a high fluidity and good segregation resistance as stated before. Self-leveling mortar has a density range between 2000 and 2200 kg/m3, (L Panama, 2015) which is lower than the normal mortar, which is ranged between 2400, and 2600 kg/m3, thus it decreases the dead load. It could come with different colors to be considered as a finish layer without adding any kind of material above it.

a) Conventional mortar

b) Self-leveling mortar

Figure 1: Conventional and self-leveling mortar

Admixtures are added to self-leveling mortar to increase its workability and to decrease the viscosity of the mortar. Its flow-ability is very noticeable therefore; it can spread all over the surface very straightforwardly. In addition, polymers in such mortar mix unifies the product`s viscosity which means that the composition from the top to the bottom will be the same without facing any segregation.

Engineers now use self-leveling mortar as floor covering for industrial areas and sometimes they coat it with epoxy layer to give the color and the glow needed as shown in Figure 2. Moreover, nowadays people started using it in their houses for decoration. Also it can be used as a topping over bricks. On the other hand it can be used as a repairing material such as road pavements, and bridge cracks (Klemenc, 2010).

a) Self-leveling mortar as floor covering for industrial areas

b) Self-leveling mortar cover with epoxy layer for floor covering of garage area

Figure 2: Examples of the use of self-leveling mortar

This paper presents the results of an investigation of the properties and performance of lab prepared self-leveling mortar mixes. Several mixtures have been designed using various constituents with moderate 28-day strength of 35 MPa. Chemical and mineral admixtures have been incorporated together with limestone to enhance the flow and cohesiveness as well as improve performance. The results reveal that self-levelling mortar can be successfully produced with comparable properties to ready-to-use market product.

2. EXPERIMENTAL PROGRAM

2.1 Material Properties

The experiment program is designed to investigate the performance of different self-leveling mortar mixes. All mixtures were prepared in the university facilities and were tested using university laboratory.

Ready to use mix cement based self-leveling product: This is a self-leveling cementitious compound obtained from one of the local companies in Egypt in order to compare its performance with that of the lab made self-leveling mixtures in terms of properties, strength and cost.

Water: Ordinary municipal tap water used in washing the aggregates as well as the production and curing of the concrete mixtures.

Fine Aggregates: Local natural siliceous river sand was used.

Fine aggregates of size between 4.75 and 2.38 mm: These were used as a coarser fine aggregate to increase bonding and the overall strength of the mortar.

Cement: Type I Ordinary Portland Cement was obtained from one of the local companies in Egypt. It has the chemical properties that satisfy the Egyptian specifications as shown in Table 1.

Table1: Chemical properties of the cement used

	Average Results	Egyptian Specifications(47561/2007)
Mgo	1.2 - 1.6	
SO3	2.5% - 3.0%	Not more than 3.5%
Loss of ignition	2.0% - 3.0%	Not more than 5%
Insoluble residues	0.4% - 0.7%	Not more than 5%
Chlorides Contents	0.02% - 0.04%	Not more than 0.10%
Clinker Contents		
C3S	50 - 55%	
C2S	20 - 25%	
C3A	6.0 - 7.0%	
C4AF	11 - 13%	
Lime Saturation Factor	0.92 - 0.94	

Superplasticizer type F: A commercially-available high-range water-reducing admixture was used. It complies with ASTM C 494 Type F. It is naphthalene based and has specific gravity in the range of 1.18.
Silica fume: Silica fume was used as a supplementary cementitious material in some mixes as shown in Tables 2. The used silica fume had SiO2 content of 93% and an average particle size of 0.15 µm. It was obtained from one of the local companies in Egypt.

Fly Ash type F, Limestone, Aluminum powder and accelerator: all are powder products obtained from one of the local companies in Egypt.

2.2 Mortar Mix Design

Self-leveling mortar (SLM) matches the conventional one in some components and differs in the others. The SLM mixture consists of cement, water, sand and some admixtures. The admixtures added to the mixtures are needed to reduce bleeding, segregation and drying shrinkage as well as to facilitate the workability required and acquire the strength needed.

Many trials were done in pursuance of a mix which possesses self-leveling performance as well as high compressive strength. Table 2 shows the mix design for 10 trial mixtures which resulted in unsuccessful test results. Based on the results of these trial mixes, cement, w/c ratios, aggregate’s quantities, admixture types and proportions were modified and adjusted several times in order to reach the best four mixtures shown in Table 3. These mixtures have the finest elf-leveling performance qualities as well as the highest compressive and flexural strength and were used to conduct the rest of the lab work and cost study. Mortar mixing and casting of specimens were carried out according to ASTM standards.

Table 2: Mix design of the unsuccessful trials mixes

Mix Constituents	Mix a	Mix b	Mix c	Mix d	Mix e	Mix f	Mix g	Mix h	Mix i	Mix j
Cement (kg/m3)	500	500	500	450	500	500	450	500	500	500
w/c ratio	0.30	0.25	0.30	0.30	0.30	0.30	0.30	0.30	0.25	0.30
Water (kg/m3)	150	125	150	135	150	150	135	150	125	150
Fine Agg. (kg/m3)	900	900	800	800	900	880	800	750	750	1760
4.75 Agg. (kg/m3)	1200	1200	800	800	1200	880	880	1005	1064	0
Superplasticizer (%)	2%	2%	10%	10%	3%	10%	10%	2%	3%	10%
Silica Fume (kg/m3)	--	--	--	50	--	--	40	--	--	--
Visc. Modifier (gm/m^3)	--	--	--	20	--	--	10	--	--	==

Table 3: Mix design of the four successful mixes

Mix Constituents	Mix 1	Mix 2	Mix 3	Mix 4
Cement (kg/m3)	500	500	517	368
w/c ratio	0.30	0.40	0.30	0.30
Water (kg/m3)	150.0	200.0	241.0	110.4
Fine Agg. (kg/m3)	810	800	518	759
4.75 Agg. (kg/m3)	810	800	518	759
Superplasticizer (%)	3.00%	5.00%	3.00%	2.75%
Fly Ash (kg/m3)	--	--	172.5	92.0
Limestone (kg/m3)	--	--	230.0	92.0
Accelerator (kg/m3)	--	--	--	10.0
Aluminum Powder (kg/m3)	--	--	100.0	--

Mixtures were made with both moderate cementitious materials content as well as high cementitious content. The latter is a common practice in high quality cementitious floorings

2.3 Lab Tests

Lab tests were performed on the four successful mixes. All experiments are conducted according to the ASTM standards. The experimental work is divided into fresh tests, hardened tests and performance tests as follows:

2.3.1 Fresh Mortar Test

Slump test: The test was performed according to ASTM C143/C143M

Air Content: The test was performed according to ASTM C185

Unit Weight: The test was performed according to ASTM C270

2.3.2 Hardened Mortar Tests

Compressive Strength: Conducted according to ASTM C109 on 50x50x50 mm cubes after 3 and 28 days.

Flexural Strength: Conducted according to ASTM C3480 on 40x40x160 mm beams after 3 and 28 days.

2.3.3 Performance Tests

Abrasion Test: This test gives an indication of the relative wear resistance of the mortar when it is used as a floor toping. The specimens were cubes with dimensions 50x50x50 mm and the applied load was about 30 N. Each cube was weighed before and after the test. The test is performed according to ASTM C944.

Rapid Chloride Permeability: This test determines the mix's ability to infiltrate chloride ions which will be determined based on the charge passing through the sample. The test is performed according to ASTM C1202. Two cylinders per mix were tested. This test is essential especially for Mix 3 and Mix 4 because they were blended with limestone.

Shrinkage Test: This test is used as a measure of the decrease in length of test specimens under controlled drying conditions, after an initial period of moist curing. The shrinkage measurement method was an adaptation of ASTM C 1148. Mortar specimens were 25x25x300 mm. Two brass studs were embedded in the fresh mortar. The length changes were measured between the two studs. A comparator (resolution 0.001 in) was used. During the first 24 hours the specimens were kept covered in their molds and they were de-molded after 24 hours and were left to cure in water and then in air and the measurements started immediately after curing and were taken after 4, 11,and 18 days.

Leveling test: This is a nonstandard test in which the flow-ability of the best mix is tested through pouring on 1.5x1.5 m^2 slab.

3. TEST RESULTS AND DISCUSSION

3.1 Fresh Mortar Test Results

The results of the fresh mortar tests for the four successful mixes are shown in Table 4. The results of unit weight came somewhat similar for all four tested mixtures. However, both slump and air content values were not similar. The mixtures had slump values in the range of 54 to 85 mm. Mix 3 had the largest slump of 85mm. The air content varied in the range of 1.6 to 3%.

Table 4: Results of the fresh mortar tests

Test	Mix 1	Mix 2	Mix 3	Mix 4
Slump/Flow (mm)	54	60	85	67
Unit Weight (kg/m3)	2284	2290	2310	2340
Air Content (%)	2.8	3.0	2.0	1.6

3.2 Hardened Test Results

3.2.1 Compressive Strength Test Results

The results of the compressive strength for the four successful mixes are given in Figure 3. The compressive strength results varied for the four mixes. Mix 1 had a relatively low compressive strength compared to Mix 3 and Mix 4. Furthermore, Mix 2 had an unexpectedly very low compressive strength. This low compressive strength for Mix 2 could be attributed to the use of 5 % superplasticizer in the mix which is relatively a high dosage. This mix is thought to have gained its maximum compressive strength early in time unlike what should have happened. On the other hand, both Mix 3 and Mix 4 attained high compressive strength. Mix 3 attained the highest compressive strength of about 38 MPa which is nearly the same as the compressive strength of the ready-to-use commercial mix available in the market.

3.2.2 Flexural Strength Test Results

The results of the flexural strength for the four successful mixes are shown in Figure 4. The flexural strength values for the four mixes were comparable to that for the ready-to-use commercially available mix The ready-to-use mix have a strength of 8 – 10 MPa and the results of the lab mixes were 10 MPa for mixes 1, 2, and 3 while Mix 4 attained flexural strength of 12MPa, which is even a higher that of the ready-to use commercial mix.

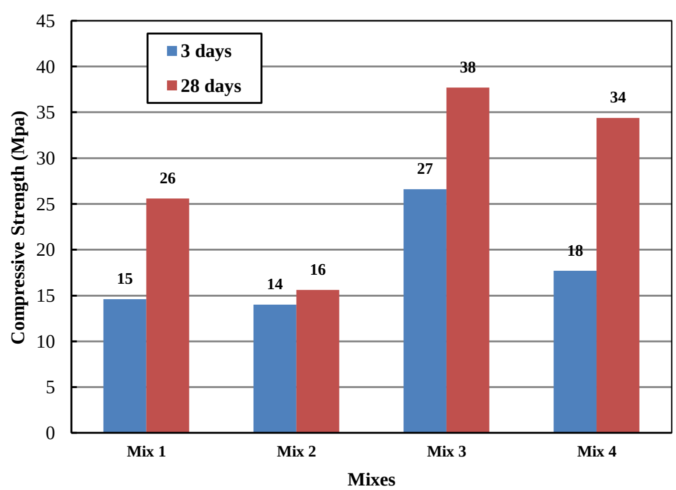


Figure 3: Compressive strength test results

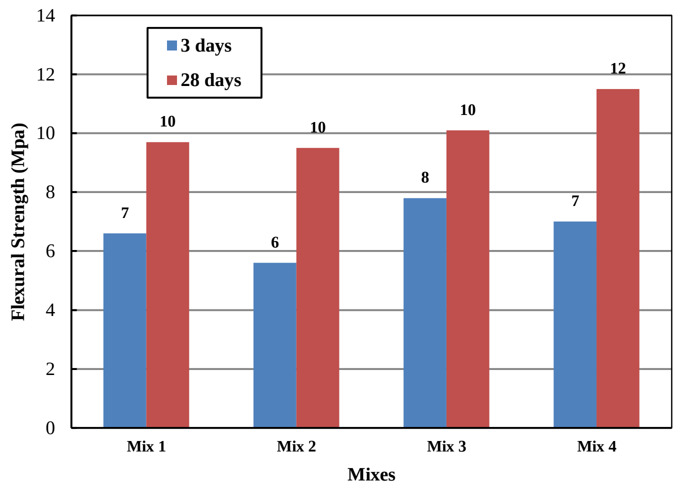


Figure 4: Flexural strength test results

3.3 Performance Test Results

3.3.1 Abrasion Test Results

The performance of the mortar cubes was assessed by means of visual inspection and loss of mass which, according to ASTM standards, should not exceed 7%. Figure 5 shows the percentage mass loss for the four mixes. Mix 2 had the highest percentage of mass loss of 6.0% followed by Mix 1 which had 5.0%. Then Mix 4 which had 4.8%. Mix 3 had the lowest percentage of mass loss of 4.5%. Accordingly, the percentages of mass loss for the four mixes were below the ASTM limit and are acceptable.

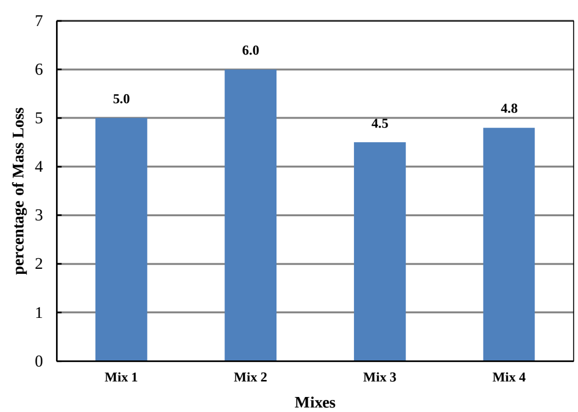


Figure 5: Abrasion test results

3.3.2 Rapid Chloride Permeability Test Results

The results obtained were judged according to table 5. Figure 6 shows the rapid chloride permeability test results. For Mix 1and Mix 2, the charge passing was 2614 and 2677 coulombs respectively, which means that the chloride permeability is moderate. While for Mix 3 and Mix 4 the charge passing was 1322 and 1709 coulombs respectively which mean that the chloride permeability is low.

Table 5: Rapid Chloride Ratings

Charge Passed (Coulombs)	Chloride Ion Permeability
> 4,000	High
2,000 – 4,000	Moderate
1,000 – 2,000	Low
100 – 1,000	Very Low
< 100	Negligible

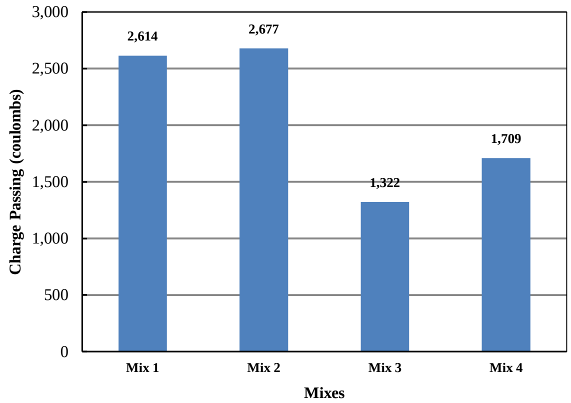


Figure 6: Rapid chloride permeability test results

3.3.3 Shrinkage Test Results

Figure 7 shows the shrinkage test results. This test was not performed on Mix 2 as the sample disintegrated while unmolding due to the excessive use of super plasticizers. Mix S1 shrank significantly more than the other mixes. There are no significant performance requirements for shrinkage therefore these percentages are acceptable. However, the likelihood of cracking will increase with the amount of shrinkage.

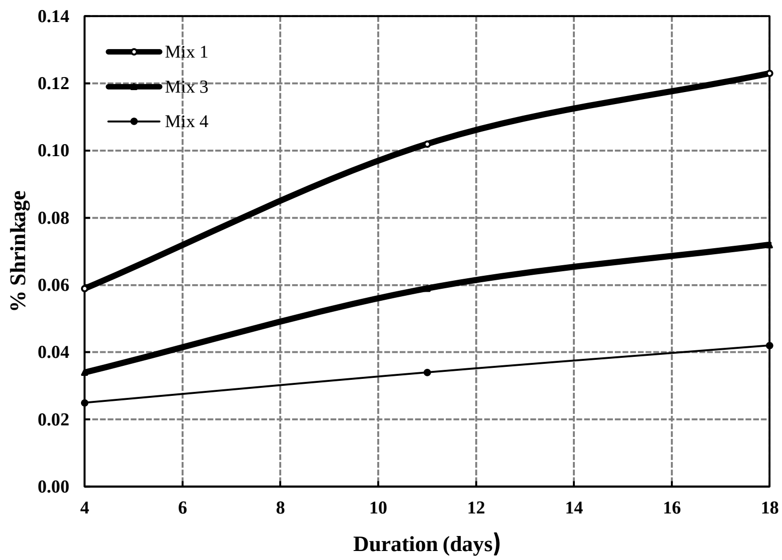
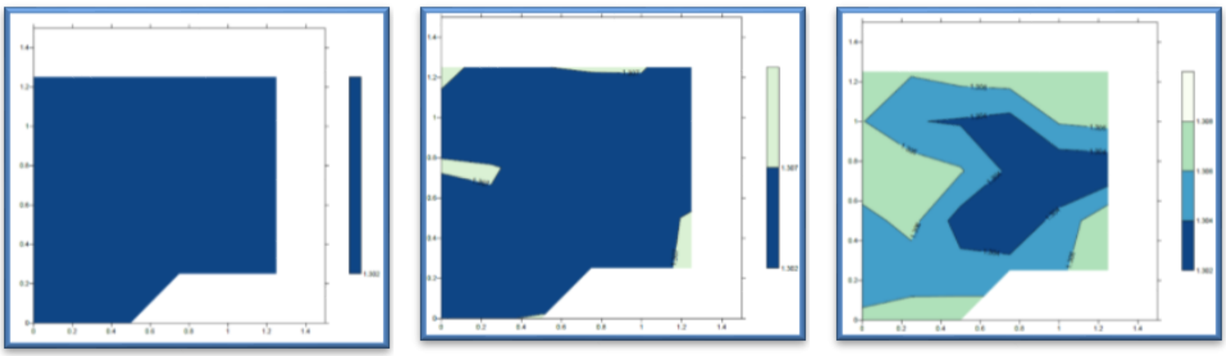


Figure 7: Shrinkage test results

3.3.4 Leveling Test Results

This is a nonstandard test in which the flow-ability of Mix 3 is tested through pouring a 150x150 cm^2 slab. Digital leveling was used to take readings of the actual top of slab level at 49 points located on 25x25 cm grid. Contour maps for the thickness were produced using the surfer program. Three contour maps were constructed for different deviations 10mm, 5mm and 2mm. For a slab thickness (t), the area within each contour line determines the area of the slab with a thickness (t – the deviation indicate by the contour line).

There was no deviation at 10mm (the area within the contour covers most of the slab). As for 5mm, there were minor deviations detected, while the largest deviation was detected to be at 6mm. As shown in Figure 8, it is clear that the slab deviation ranges from 1 mm to 5mm. Getting a deviation of 5mm in the thickness of a slab, which did not have any compaction or any usage of vibrators while placement, makes the deviation acceptable.



a) 10mm b) 5mm c) 2mm

Figure 8: Contour maps for 10mm, 5mm, and 2mm deviations

Due to the lack of capabilities, the slab was not casted at once; however it was casted on three portions. Accordingly, this deviation would have been avoided if the slab was cast at once.

4. COST ESTIMATE STUDY

A cost comparison study was performed to compare the cost of the lab prepared mixes with that of the conventional mortar flooring and that of the ready-to- use mix available in the Egyptian Market.

A cost estimate model was developed which accounts for the cost of the material and the cost of preparation and installation equipment and labor. A simple computer program was developed to estimate the total cost of the mixture. The input for this program is the constituents of the mix, thickness of the mortar layer, and the area to be covered. The computer applies the unit cost for each component, the cost of equipment to be used and the cost of labor and responds with output in the form of the total cost of the mix to cover the specified area. The unit cost of the different material component, cost of equipment, and cost of labor are pre-stored in a data base in the program. Multiple suppliers and experts in the market were surveyed to generate costs for the different items which are stored in the data base of this cost estimate model. It is assumed in this model, based on the experts' survey, that the conventional mortar requires 3 persons to cover an area of 70 m^2 while the lab prepared mixtures require only 2 and the available ready-to-use mix requires 3 labors. Only needed equipments that differ from one mixture to the other are included in the cost estimate model. Equipments which are the same for all types are not included as the interest is only in the differences in cost. Example for such equipment that is not included is the mixer as it is needed for all mixtures. In case of the lab self-leveling mixtures the mob price is neglected as it is very low compared to the rest of the items included in the cost estimate study.

The developed cost estimate model was used to estimate and compare the cost of the conventional mortar mix, the lab self-leveling Mix 3, and the ready-to-use mix available in the Egyptian market. Table 6 show the results of the cost estimate model for the conventional mortar mix, the lab self-leveling Mix 3, and the ready-to-use commercial mix available in the Egyptian market. The cost estimate was based on production of 1.25 m^3 of the mix to cover an area of

$25m^2$ with 5 cm thick of the mix, The results in Table 6 show that The cost of the self-leveling Mix 3 prepared in the lab and investigated in this cost estimate turned to be higher than the conventional mortar but much less than the ready-to-use mix available in the Egyptian market. This is mainly because cost of the ready-to-use mix material is about five times that of the lab mixture material.

Table 6: Comparison between the costs of the different mixes as obtained from the cost estimate model

Mix Type	Breakdown					Productivity Per Day (m^2/day)	Duration (Days)	Cost LE
	Item		Unit	Unit Cost LE	Quantity			
Conventional Mortar Flooring	Labor		Day	120	2	25	1	240.00
	Materials	Cement	Ton	600	0.625	N/A	N/A	375.00
		Fine Agg.	Ton	50	2.125	N/A	N/A	106.25
	Equipment	Vibrator	Day	100	1	135	1	100.00
				Total Cost				821.25
Lab Self-leveling Mix	Labor		Day	120	1	25	1	120.00
	Materials	Cement	Ton	600	0.625	N/A	N/A	375.00
		Fine Agg.	Ton	50	2	N/A	N/A	100.00
		Limestone powder	kg	1.5	287.5	N/A	N/A	431.25
		Aluminum Powder	kg	0.2	62.5	N/A	N/A	12.50
		Fly Ash	kg	1.4	216.25	N/A	N/A	302.75
		Super Plasticizer	L	3.7	19.375	N/A	N/A	71.69
	Equipment	Mob	N/A	N/A	N/A	N/A	N/A	0.00
				Total Cost				1,413.19
Ready-to-use Commercial Mix	Labor		Day	120	2	25	1	240.00
	Ready-to-use Mix		Bag	250	32	N/A	N/A	8000.00
	Equipment	Trowel	Day	130	1	120	1	130
				Total Cost				8240.00

While this comparison is primarily based on materials cost, yet the gap is quite wide between the cost of a ready-to-use material and one that is prepared on site. Costs of extraction, transportation and handling are expected not to exceed 20% of the materials cost, thereby maintaining the remarkable cost advantage for the on-site product when compared with ready-to-use product.

5. CONCLUSIONS

Base on the materials, procedures and other aspects incorporated in this study, the following can be concluded;

1. Lab prepared self-leveling mixtures have high flow-ability and can be placed without the need for vibration. This in turn allows to save energy and to ensure a suitable cast-in-place. Moreover these self-leveling mixtures are high performances mixtures which spread out on the area with less segregation and minimal bleeding.

2. The performed cost estimate indicates that the lab prepared self-leveling mortar has higher initial cost compared to conventional mortar mixtures. However, they are indeed less costly when taking longer life span and performance with minimal maintenance into consideration.

3. Self-leveling mixtures prepared in the lab are less expensive compared to the considered ready-to-use mix available in the market. These mixtures need less labor as it does not need any vibration or any use of equipment while placement. Only a mob could be used for placement in large foot print areas to ensure the mortar is spread all over the area.

4. Based on the characteristics and performance of self-leveling mortar, it can be predicted that self-leveling mortar will be more commonly used due to its higher degree of flatness and smoothness as required by floor coverings products which are expected to increase in the years to come.

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