ISBN: 978-628-95207-4-3. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2023.1.1.1242

Sprayed mortar design to optimize plastering in confined masonry walls

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***Abstract*— Plastering is a procedure that makes it possible to standardize surfaces and fill in the voids to ensure a good finish on masonry walls, as well as increasing their strength and durability. However, this activity generates large amounts of waste related to the loss of material during this construction process. Therefore, it is necessary to implement new technologies to reduce costs and execution times, in addition to obtaining the appropriate properties to protect the surface. In the present investigation, the technology of projected mortar for plastering is presented as an innovative alternative to the traditional system. For this reason, twelve sprayed mortar mixtures are designed with w/c ratios of 0.45 and 0.50, Type I and Type V cement contents, accelerator admixtures and superplasticizer admixtures; mixtures that are tested in the laboratory to propose an optimal mixture according to its properties in the fresh and hardened state. Finally, through unit cost analysis, an estimate of the savings in time and cost that the projected mortar technology presents in comparison with the traditional method for plastering is obtained.**

***Keywords*—Sprayed mortar, plastering, wall finishes, tests, mortar spraying machine.**

I. Introduction

Finishing processes have a significant influence on the construction cost of a building, amounting to 10 to 30% of the total cost of a project, depending on the type of construction executed [1]. One of the items that is a part of these processes is plastering, in which the use of mixtures with adequate quality is often not guaranteed, leading to productivity losses and increased time and cost. Reference [2] specifies that the waste generated by the additional thickness of mortar in the plastering activities of interior and exterior walls and ceilings corresponds to about 5% of the total cost of a building, while waste from non-optimized dosages of plastering and coating mortar corresponds to approximately 2%. On the other hand, Reference [3] indicates that the waste originated by the traditional plastering process corresponds to 7%. It should be taken into consideration that in the traditional plastering method, the percentages of waste are especially related to the waste of materials. However, the percentages of this waste may vary depending on the materials and equipment used, as well as the labor available for the execution. Reference [4], for instance, evaluates the material that was left over in a construction when carrying out the plastering process to calculate the mortar waste in the activity, where waste values of 14 to 24% are obtained. Nowadays, technological advances in construction have developed new options to guarantee the homogeneity of the mixture, including sprayed mortars for plastering as a proposal. With a proper mix design and provided it is placed correctly, the coating can be increased, and the properties of the mortar can be improved to generate greater strength and durability in the walls. In addition, some material can be saved by making the surface uniform because the mixture ensures adherence to the wall, resulting in minimal waste compared to the traditional plastering method.

Digital Object Identifier: (only for full papers, inserted by LACCEI).
ISSN, ISBN: (to be inserted by LACCEI).
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The final quality of the sprayed mortar depends on the quality of the mixture before being sprayed and the technique to be used, as well as its consistency, fluidity, and rheological properties. Reference [6] consists of varying the dosage of the components of a mortar and evaluating its rheological properties to improve its workability and maintain its stability. Different mixtures are designed considering the particle size, fineness modulus and shape of the aggregate, along with the addition of superplasticizer admixtures to achieve fluidity and stability of the mortar. The authors manage to improve the workability in their dosages but decrease the stability and increase the cost of the mixtures. Reference [7], on the other hand, describes the evolution of the properties of the sprayed mixtures when using different types and dosages of setting accelerators at an early age using the Ultrasonic Method. It is concluded that the tested samples present different behaviors visualized in an increase or reduction of their strengths according to the type of cement (I or II), type of admixture (superplasticizer or accelerator) and its dosage used. Reference [8] evaluates the mechanical properties of sprayed mortars elaborated with Type I cement and three types of setting accelerators (alkali-free with a dosage of 5% of cement weight, alkali-free with a dosage of 7% of cement weight or based on sodium aluminate in dissolved form with a dosage of 3% of cement weight), where the mixtures with alkali-free accelerators with a dosage of 5% show better mechanical properties. It is emphasized that the mortar must maintain an adequate workability to be sprayed without interruptions, allowing it to reach the required strengths.

Unlike the aforementioned investigations, in this study two types of cement (Type I and Type V), two types of setting accelerator admixtures and two types of superplasticizer admixtures are used to design twelve sprayed mortar mixtures. The purpose is to evaluate the properties that the sprayed mortar must have both in the fresh and hardened state to ensure the quality of the finishes in masonry buildings. In the fresh state, it is important to analyze the workability and consistency of the mixture; while, in the hardened state, its adherence, durability and compressive strength must be evaluated. It is also intended to estimate the savings in time and cost of the sprayed mortar method compared to the traditional plastering method, by means of the unit cost estimating corresponding to each item. The materials and tests of this research are carried out in the city of Lima, capital of Peru, according to the regulations for each procedure.

II. Methodology

The present research is experimental. The different properties of the sprayed mortar designs are evaluated by means of fresh and hardened tests carried out in the laboratory. The independent variables are established, where the water-cement ratios, the type of cements (I and V) and the types and dosages of admixtures (superplasticizer and accelerators) are considered. Likewise, the dependent variables are established, considering the properties of the mortar, such as workability and compressive strength. In this way, the independent variables are manipulated to evaluate their effect on the behavior of the mortar mixtures.

First of all, the characterization of the materials used to prepare the mixtures is carried out. This includes Portland cement Type I with a specific surface area of 336 m^2/kg and air content of 6.62%; and Portland cement Type V with a specific surface area of 352 m^2/kg and air content of 5.12%. These are used for the sprayed mortar mixtures in ranges from 470 to 522 kg, considering the requirements established in NTP 334.009 [9]. Likewise, potable water is used to prevent possible contaminating agents from entering the mixture, in compliance with NTP 339.088 [10]. The fine aggregate used for mixes 1 to 8 comes from Agrecon quarry, while for mixes 9 to 12, it comes from Jicamarca quarry. In accordance with NTP 400.037 [11], these aggregates are tested to determine the particle distribution range, fineness modulus and maximum aggregate size, by means of the gradation test, according to the procedure established in NTP 400.012 [12]. Likewise, the moisture content test is carried out according to NTP 339.185 [13], unit weight test according to NTP 400.017 [14] and specific weight and absorption according to NTP 400.022 [15]. Finally, in accordance with ASTM C494 [16], MasterEase 3910 and MasterRheobuild 1201 superplasticizer admixtures are used, along with MasteRock SA 160 and MasterXseed 100 accelerator admixtures.

For the mixture designs, the dosages of cement, potable water, fine aggregate, and admixtures are calculated. The technical specifications for preparing the designs consider w/c ratios of 0.45 and 0.50, two types of cement, 235 liters of potable water, fine sand and accelerator and superplasticizer admixtures. These mixtures must comply with the specifications stipulated in ACI 506R-16: Guide to Shotcrete [17]: slump of 7 to 9 inches, air content of 3 to 8%, temperature of 15 to 25°C and minimum compressive strength of 200 kg/cm^2.

Subsequently, tests in the fresh state are performed: temperature test according to NTP 339.184 [18], flow test according to NTP 339.085 [19] and slump test according to NTP 339.035 [20], in order to evaluate the consistency, degree of fluidity of the mixture and workability of the mortar. On the other hand, specimens are prepared, as shown in Fig. 1, to continue with the hardened state tests. The penetration test is performed according to NTP 339.082 [21], to determine the setting time of the mixture; splitting tensile strength test according to NTP 339.084 [22], to determine the maximum stress that the specimen can withstand; and the compressive strength test according to NTP 339.034 [23], to determine the maximum resistance capacity of the mortar to the application of an axial load. The mixture must have an adequate compressive strength to be able to withstand the weight of the masonry and even higher loads in case of load-bearing walls. Considering the properties of the mixes, one is selected as the optimum mixture.

Fig. 1 Mortar specimens for hardened state testing.

Finally, a comparison is made between the optimized design of sprayed mortar considering the selected mixture and the traditional plastering method. For the evaluation of the sprayed plastering method, a unit cost estimation is carried out, considering the performance of the corresponding spraying machine. On the other hand, the unit cost estimation for the traditional method is performed. In this way, the benefits of the sprayed mortar proposal are revealed considering the time and cost of its execution.

III. Results

A. Sprayed Mortar Designs

Twelve mix designs are defined, considering two types of cement, Type I and Type V; two types of water/cement ratios, w/c=0.45 and w/c=0.50; two types of superplasticizer admixtures, MasterEase 3910 and MasterRheobuild 1201, referred to as A-S1 and A-S2 in the tables, respectively; and two types of accelerator admixtures, MasteRock SA 160 and MasterXseed 100, referred to as A-A1 and A-A2, respectively. In the same way, a nomenclature is assigned to each mixture, where the dosage of each one can be seen in Tables I and II.

TABLE I
Design for mixes 1 to 6

	M1	M2	M3	M4	M5	M6
w/c	0.50	0.50	0.45	0.45	0.50	0.50
Cement T-I (kg)	470	470	522	522		
Cement T-V (kg)					470	470
Water (kg)	235	235	235	235	235	235
Sand (kg)	1458	1458	1417	1417	1460	1460
A-S1 (%)	0.39		0.39		0.44	
A-S2 (%)		1.82		1.94		1.82
A-A1 (%)	1.00		1.00		1.00	
A-A2 (%)		1.00		1.00		1.00

TABLE II

DESIGN FOR MIXES 7 TO 12

	M7	M8	M9	M10	M11	M12
w/c	0.45	0.45	0.50	0.45	0.50	0.45
Cement T-I (kg)			470	522		
Cement T-V (kg)	522	522			470	522
Water (kg)	235	235	235	235	235	235
Sand (kg)	1419	1419	1548	1504	1551	1507
A-S1 (%)	0.50					
A-S2 (%)		1.94	1.82	1.82	1.82	1.82
A-A1 (%)	1.00			1.00		1.00
A-A2 (%)		1.00	1.00		1.00	

B. *Unit Weight and Air Content*

The values of air content in the mortar mixes range from 4.5 to 8%. According to the specifications indicated in Reference [17], the values must be in the range of 3 to 8%. Fig. 2 shows that M7, with Type V cement and w/c ratio of 0.45, has the highest percentage of air, while M11, with Type I cement and w/c ratio of 0.45, has the lowest percentage of air. This parameter influences the workability of the mixture.

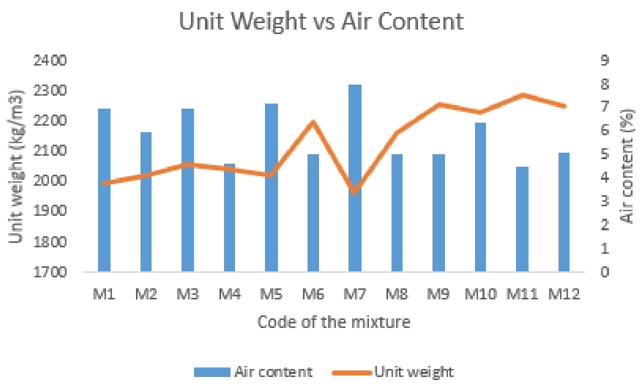

Fig. 2 Unit weight and air content for each mixture.

C. *Slump and Fluidity*

In the slump test performed on the mortar mixtures, values between 7 and 8 inches are obtained. As specified by Reference [17], slump values should fluctuate in the range of 180 to 220 mm, i.e., 7 to 9 inches. Fig. 3 shows that regardless of the type of cement used and the w/c ratio, the consistency of all the mixtures presents similar values.

The flow test carried out indicates that the values of each mixture are in the range of 156.9 a 186.4%. Therefore, it is evident that the mixes with the highest flowability are M11 and M12, with 177.6 y 186.4%, respectively, both made with Type V cement. On average, it is observed that the mixes with Type V cement have greater fluidity, with 169.5%; while the mixes with Type I cement have an average fluidity of 161.65%.

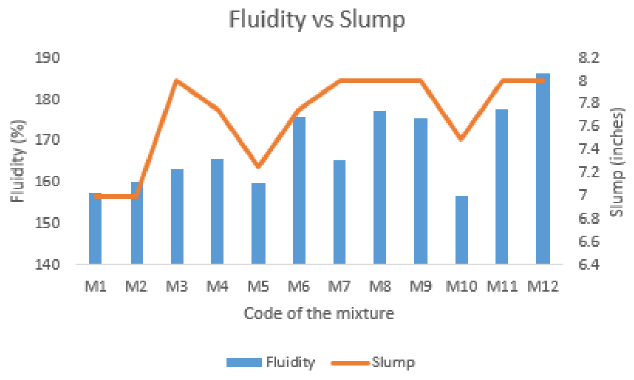

Fig. 3 Fluidity and slump for each mixture.

D. *Compressive Strength Vs Tensile Strength*

Fig. 4 shows the compressive strength development of the twelve mixes from day 1 to day 28. At the age of 28 days, the compressive values of the twelve mortar mixtures obtained from the tests fluctuate between 279 y 544 kg/cm^2.

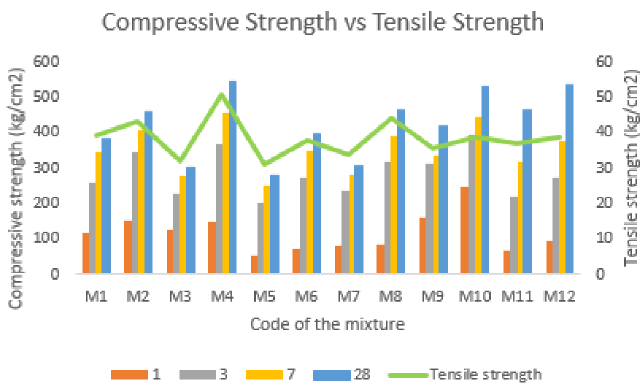

Fig. 4 Compressive and tensile strength at 1, 3, 7 and 28 days.

Reference [23] is a guide for wet mixes at 28 days that establishes that compressive strength values must be in the range of 200 to 700 kg/cm^2. It can be observed that the mixtures made with Type I cement have higher strengths at day 1 than the mixes made with Type V cement. However, on the third day all the mixtures exceed the minimum of 200 kg/cm^2 specified by the referred guide.

On the other hand, the tensile values of the twelve mortar mixes obtained from the tests range between 28 and 44 kg/cm^2 at 7 days and between 31 and 51 kg/cm^2 at 28 days. These values are not very high, since tensile strength is not a main characteristic of the mixture since mortar works better in compression than in tension.

E. *Penetration Resistance*

The setting times of the twelve mortar mixtures obtained from the tests are shown in Fig. 5, which range from 5:30 hours to 7:20 hours for the initial setting time and from 6:08 hours to 8:20 hours for the final setting time. The minimum setting time difference is 0:36 hours, while the maximum is 1:18 hours. The graph shows that the mixes with Agrecon aggregate with a fineness modulus of 2.73 and Type I cement, on average, have a faster initial setting than the mixtures made with Type V cement with the same aggregate.

Likewise, the final setting of the mixtures made with Type V cement is on average slower than those with Type I cement.

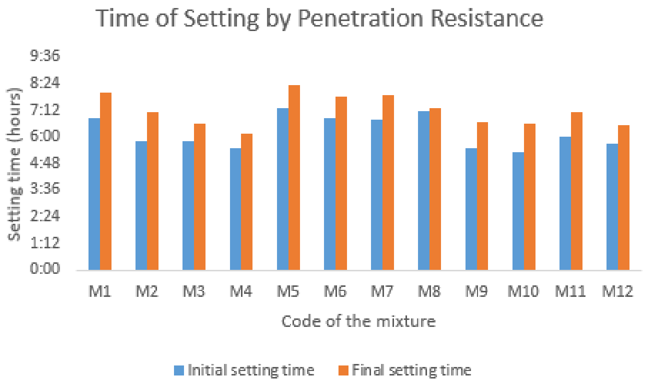

Fig. 5 Initial versus final setting time.

F. *Selection of the Optimal Design*

The mortar mixtures are classified according to the results obtained in the fresh and hardened tests. To assign a score to each mixture, an ideal value is taken within the range established by the standards, which represents a 100%, as shown in Table III.

TABLE III
REPRESENTATIVE VALUES AT 100%

Performance	Air content (%)	Fluidity (%)	Slump (inches)	Temperature (°C)
1	5.5	165	8	21
Compressive strength (kg/cm^2)	Tensile strength (kg/cm^2)		Initial setting time (hours)	Final setting time (hours)
>210	38		06:00	07:40

Based on these values, a compliance percentage is assigned for each property analyzed. It should be considered that the score of the mixture is higher when the percentage obtained is closer to 100%. Then, the graph shown in Fig. 6 is elaborated, where the tests performed and the percentage of compliance for each mixture can be observed graphically. From this ranking, it its recognized that the optimal mixture is the one with code M11.

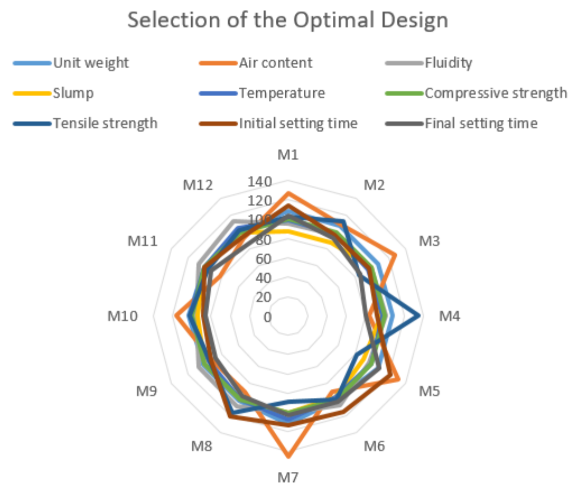

Fig. 6 Graph for the selection of the optimum mixture.

G. *Time and Cost Savings*

Table IV shows the unit cost for plastering with traditional mortar. A performance compiled from a construction site in Lima is considered, which is 17.6 m^2/day for plastering and 34 m^2/day for covering. Likewise, the use of Portland cement Type I, the use of fine aggregate Jicamarca and 1:5 mortar with 1.5 cm joint is taken into consideration. The crew also includes 0.1 Foreman, 2 Operator and 1 Laborer. Also, a 7% waste is considered to obtain the actual volume of mortar.

TABLE IV
UNIT COST ESTIMATING FOR TRADITIONAL WALL PLASTERING

	Unit	Crew	Quantity	Unit Cost	Partial Cost
Labor					45.94
Foreman	LH	0.1	0.069	28.19	1.94
Operator	LH	2	1.380	23.49	32.41
Laborer	LH	1	0.690	16.79	11.58
Materials					3.981
Cement	kg		0.119	26.50	3.147
Sand	m^3		0.017	45.00	0.758
Water	L		4.300	0.018	0.076
Equipment					1.378
Hand tools	%Labor		0.030	45.94	1.378
				Total S/.	51.30

Subsequently, the unit cost is calculated for the sprayed mortar with the proposed optimum mixture M11. In the tests carried out by the company Thiessen, the performance using the Mini Avant spraying machine is 70 m^2/day with a crew of 2 Operator and 1 Laborer. Therefore, this performance is considered to elaborate the item shown in Table V. Likewise, to obtain the actual volume of mortar, an approximate waste percentage of 3% is considered.

TABLE V
UNIT COST ESTIMATING FOR SPRAYED WALL PLASTERING

	Unit	Crew	Quantity	Unit Cost	Partial Cost
Labor					7.228
Operator	LH	2	0.229	23.49	5.369
Laborer	LH	1	0.114	16.79	1.919
Materials					7.367
Cement	kg		0.171	26.50	4.528
Sand	m^3		0.015	45.00	0.671
Water	L		3.631	0.018	0.064
Admixture S2	L		0.131	10.50	1.379
Admixture A2	L		0.073	10.00	0.726
Equipment					20.790
Hand tools	%Labor		0.030	7.288	0.219
Mini Avant	MH	1	0.114	180.00	20.571
				Total S/.	35.45

To determine the economic feasibility of using sprayed mortar for plastering, its application is compared in terms of time and cost with the traditional method. This evaluation considers a construction project where 500 m^2 need to be plastered, as well as the traditional plastering performance of 17.6 m^2 per workday and the sprayed mortar performance of 70 m^2 per workday using the Mini Avant machine. Table VI shows that conventional plastering for 500 m^2 can be done in 29 days. In contrast, with the sprayed mortar method, the activity can be done in 8 days. Therefore, there is a 72% time-related saving.

TABLE VI
TIME IN PLASTERING

	Area	Performance	Time
Traditional plastering	500 m^2	17.6 m^2/day	29 days
Sprayed plastering	500 m^2	70 m^2/day	8 days

Likewise, with the unit cost estimating previously developed, it is possible to obtain the cost per square meter for conventional and sprayed plastering. Considering the rental of the spraying machine, although the cost of materials and equipment are lower in traditional plastering, the sprayed mortar technique is more economical because labor in the traditional method is more expensive. As shown in Table VII, the total cost of traditional plastering for a 500 m^2 wall is S/. 25 647.64, while the total cost of sprayed plastering is S/. 17 722.70. Therefore, there is a 30.90% cost-related saving in the sprayed mortar method.

TABLE VII
COST IN PLASTERING

	Area	Performance	Cost
Traditional plastering	500 m^2	17.6 m^2/day	S/. 25 647.64
Sprayed plastering	500 m^2	70 m^2/day	S/. 17 722.70

IV. CONCLUSIONS

Based on the results obtained, it is concluded that the twelve mixtures tested meet the minimum requirements established by the Shotcrete Guide for the fresh and hardened state, with the mixes made with Type I cement having a better initial compressive strength. However, regarding the mixture designs tested, the mortar with properties closest to what is expected is M11, with a w/c ratio of 0.50, with 470 kg of Type V cement, 1551 kg of sand, 1.82% of MasterRheobuild 1201 superplasticizer admixture and 1% of MasterXseed 100 accelerator admixture. This mortar exhibits the best rheological behavior, with a slump of 8" and a fluidity of 177.6%, in addition to strength levels above 200 kg/cm^2. Likewise, the sprayed plastering method allows to obtain up to 72% savings in time and up to 31% savings in cost compared to the traditional plastering method.

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