A RHEOLOGICAL STUDY ON HAND MIX AND SPRAY MORTAR

B.Tech Project

by

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Certificate

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Abstract

The purpose of this study is to find the best possible mix design using the K-factor theory for hand and spray applications of mortar on masonry surfaces. The study starts with literature review, the w/c ratios 0.48, 0.54, 0.6 and 0.7 used in the previous studies are adopted. Water content in the mix designs varied from 235 to 255 kg/m3 to 275 kg/m3. Similarly fly ash content was varied from 0 to 45% in which total powder content was kept constant. Workability was identified of these mixes which are significant enough to be applied on the masonry surfaces by means of hand and spray applications. compressed air was used for spray applications and trowel was used for hand applications. Workability was identified in terms of slump which has a maximum height of 150mm.

It was found that the slump for application of mortar on the masonry surfaces by means of hand ranges from 0 mm to 50-60mm, similarly for spray applications slump ranges from 30mm to 85-90mm.

It was found that admixture dosage decreased as increasing the fly ash content up to 35%, thereafter the dosage was decreasing in which slump was kept strictly constant. As after increasing the fly ash content above 40% the cohesivity of the mix was very high and theses mixes were less adhesive to be applied on the surfaces.

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CHAPTER 1

INTRODUCTION

1.1 Background

To enhance the durability, aesthetics and structural integrity of the infrastructure and constructed building elements. Mortar, Plaster, Shotcrete, and repair materials plays vital role in the construction industry. Mortar is a blend of cementitious materials, fines, and water in addition to the additives for the specific properties. It serves as an adhesive material and provides a structural durability. Mortar can be made of different materials such as Portland cement, Lime, and Cement-lime as a binding material which makes them preferable for different applications [1, 2].

Plaster is a construction material applied on the surfaces to protect the underlying surfaces and to provide the elegant surface. It is the proper proportion of lime, gypsum or fines and cement which is the mixed with water to get a paste. It offers a smooth and stable surface to the constructed building element. [3]

Sprayed concrete, or shotcrete, is a construction method that utilizes a high velocity spraying process to cover surfaces with a blend of water, cement, and aggregates. Slope stabilization, underground tunnel support, and architectural finishes are just a few of the many uses for this adaptable technique. The shotcrete tactics promote exceptional bonding and fast construction, which are essential in tricky settings and intricate structures. [4, 5]

1.2 Problem Statement

The objective of this research is to investigate the critical issues in the construction industry through a rheological analysis of spray mortar and hand mix mortar. Determining the optimal range of admixtures for a particular mortar mix design, thereby assuring its spray ability, is the primary objective. In an effort to establish sprayable plasters as a viable substitute, this research examines the rheological characteristics of mortar as it is sprayed, with a particular focus on the time-saving potential it may have for extensive construction endeavours. The experimental design incorporates methodical fluctuations in water-cement ratios, powder content, admixture content, and water content, thereby providing a thorough comprehension of their interrelation and influence on the performance of mortar. The objective of this study is to provide critical insights that have the potential to transform plastering techniques, specifically in the context of extensive construction projects.

1.3 Objectives

The Main objective of this thesis is to study the alternate mix design possibility for Mortar which can be applied on the existing surfaces by means of hand and spray. The well-defined objectives of this thesis are as follows:

1. To investigate the rheological parameters of the mortar mix prepared which is applicable for spraying and hand applications.
2. To investigate variations in different parameters like w/c ratio, water content, admixture content and powder content on the slump value.

1.4 Scope of Study

This thesis focuses on the alternate mix designs involved in the preparation of mortar, which is used as plaster material, and which can be applied on the brick masonry walls by means of trowel (hand) and spray (shotcrete). Durability and mechanical tests will be conducted on the specimens of same design mixes which are casted by means of hand without any vibrations used and by spraying (Shotcrete).

1.5 Thesis Organisation

This study is Composed of five chapters which are enumerated below:

Chapter 1 highlights the background of study, problem statement is elaborated in brief which gives an idea for the need of the study, scope of the study is described which enumerates the various aspects of the study. Objectives of the study are interpreted to highlight the goals to be achieved at the end of the study.

Chapter 2 highlights the multifaceted applications of cost-effective and durable mortar in civil engineering, covering structures such as duct drains, wells, shafts, walls, and pavements. It investigates the use of both modern mortar spraying machinery and manual methods for plastering. The study delves into plaster mortar mix design, additive impacts, and optimization experiments on fly ash and plasticizers for workability and compressive strength. Traditional Portland cement and waste materials from rice and sugar mills are thoroughly examined. The chapter concludes with an analysis of newly prepared mortar's workability using the Bingham model, shedding light on its performance in civil engineering applications.

Chapter 3 highlights the experimental methodology. Materials used are described in detail with their physical and chemical properties confirming to the Indian standards of practice in addition to that specimen preparation is discussed. In addition to this batching of materials in which mix design methodology, mixing operations and workability measurements are elaborated. Furthermore, different ways of application of mortar on the surfaces are discussed.

Chapter 4 highlights the mix design matrix adopted, Workability results are discussed in which effect of admixture on slump, admixture demand at different water content are elaborated in detail. In addition, effect on slump at different water content are discussed. Furthermore admixture demand at different fly ash dosages are elaborated in detail.

Chapter 5 concludes the systematic exploration of mix design considerations for hand and spray applications of mortar. Findings highlight the delicate balance required for optimal cohesivity and adhesiveness, offering practical insights for informed mix design decisions in masonry construction.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a thorough examination of mortar as a multifunctional plaster material commonly utilized in various civil engineering applications. Further elaborating on its cost-effectiveness, durability, and ease of manufacturing, mortar is being investigated for its potential use in a wide range of structures, such as duct drains, wells, shafts, walls, and pavements. The discourse encompasses several techniques employed in the field of plastering, ranging from traditional and manual application methods to the utilization of advanced mortar spraying machinery. This study investigates the mix design of plaster mortar, with a focus on the incorporation of additives and their influence on mechanical and thermal qualities. This study investigates the significance of fly ash and plasticizers in relation to workability and compressive strength, while also examining the impact of optimization experiments. The study materials encompass conventional Portland cement as well as by-products derived from rice and sugar mills, which are thoroughly described. Furthermore, the chapter explores the characteristics of newly prepared mortar, with a particular focus on its workability and the use of the Bingham model as a means to comprehend its performance. In general, these observations offer a fundamental comprehension of the performance of mortar in various civil engineering scenarios.

2.2 Mortar as a Plaster material

Mortar has been used for a wide range of applications in the civil engineering industry. Plaster plays an important role in padding, protective and bonding to constructed structures. In view of the fact that it is low cost, increased strength and simple fabrication, It has been applied as a alienating lining materials in duct drains, wells, shafts, walls, Pavements supporting materials etc[6].

2.2.1 Plastering

This section elaborates the different ways of plastering the surfaces with detailed experimental procedures.

2.2.1.1 Untrained Plaster

This is a normal practice of plastering the surface in this type of plaster cement and sand is mixed with approximate amount of water based on the experience on mason on the ground without following the and design mix. It generally has M15 grade of mortar.

2.2.1.2 Controlled Plaster

In untrained plaster no plasticizers were used mixing was done manually on the ground but if this mixing is done using a mixer, the quality improves a s water demand reduces with the use of plasticizer thereby which increases the strength and fracture energy of the mortar.

2.2.1.3 Mortar Spraying Machine Plaster

The mortar spraying machine consists of three adjustable outlets or nozzles for the spraying of mortar mix. The inlet pipe is connected with the automatic hydraulic air compressor machine. In a research, the compressor had a maximum capacity of 400 kg/cm^2. The mortar mix was poured into the box-shaped container. At inlet when the spring-operated push-up handle is pressed, the air pressure is released pushing the mortar inside the box resulting in the uniform spraying of the mortar. The spraying machine was moved up to the panel casting yard using long pipe connected to the compressor. Fig 2.1 shows the schematic representation of the spraying mortar machine.

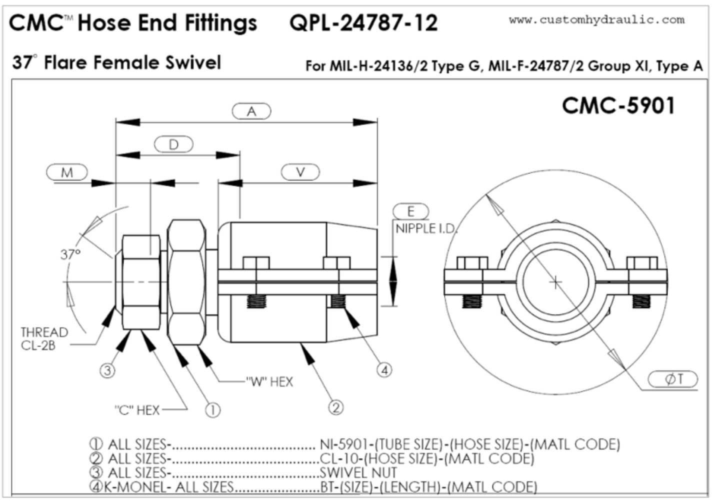

Figure 2.1: Mortar Spray Machine

2.2.2 Mix Design of mortar used as a plaster.

A study was conducted to develop a mortar with some additives to test the mechanical and thermal properties. It was found that the ratio od cement to fines in the mix is limited to 1:2.75. A certain amount of cement i.e., 5% to 30% was replaced by the bagasse ash whereas 5% to 15% with rice husk. Firstly using a mechanical mixer of approximately having 50 RPM of angular velocity is used for dry mixing of cement, Fines and additives for 5 minutes and after adding water to the dry mix again mixing was done for 5 minutes to reach the desired consistency [7]. The Water/Cement (W/C) ratio of 0.5 was adopted to cast the specimens [8].

A study shows that 1:3 cement sand mix for convention wall plastering is recommended. Closed burnt rice husk ash (CBRHA) and open burnt rice husk ash (OBRHA) were replaced by the fines from the mortar mix created Figure 2.1 below shows the mix design of the mortar adopted at different percentages of CBRHA and OBRHA raging from 10% to 50% by the weight of fines in the mix. As stated above dry mixing was done using a mechanical mixer for 5 minutes and after adding the water again mixing was done for 5 minutes [8].

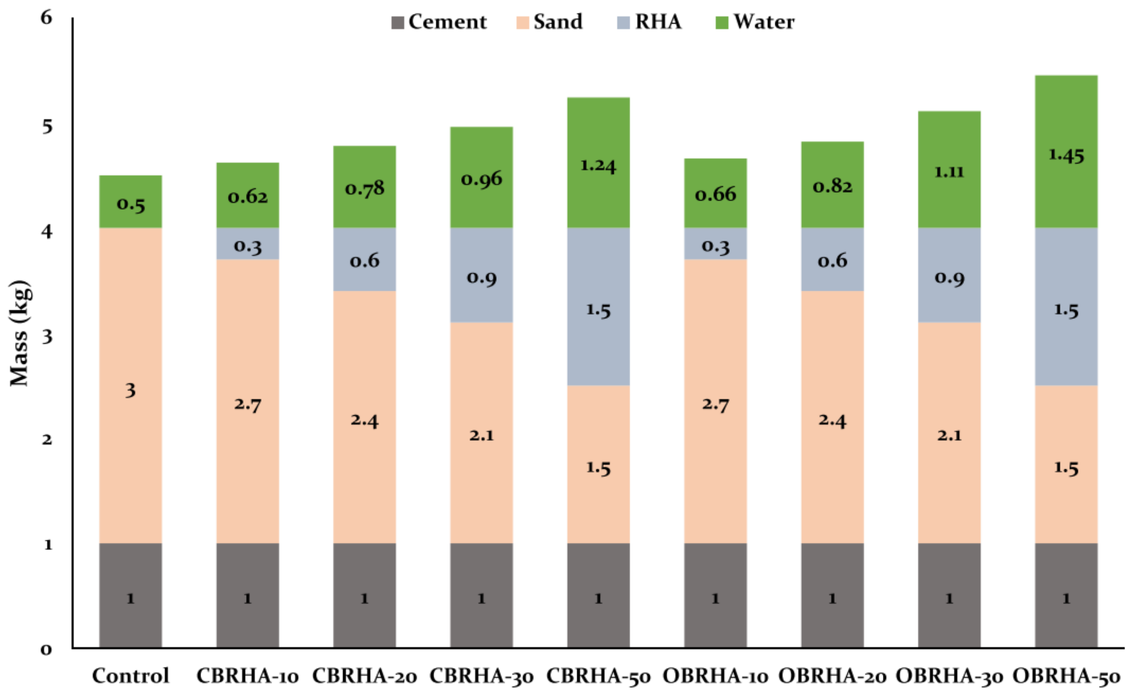

Figure 2.2: Different mix Designs of Mortar used as a plaster [8].

A study stated that binding efficiency factor or K-factor for fly ash can be adopted to evaluate the effective W/C ratio for different concrete mix designs. In this theory for a adopted fly ash percentage F the effective W/C will be W/(C+KF) such that C is the cement content in Kg/m^3 and K is the fly ash effectiveness factor and F is the fly ash content in Kg/m^3 [9]. It was considered that the similar mix design theory can be adopted for designing the Mortar for plaster applications [10].

2.2.3 Fly Ash

According to Park and Heo (2004), fly ash contains silica (SiO2) and alumina (Al2O3), making it a pozzolanic substance. Eq. 2.1 illustrates the pozzolanic process that takes place in the calcium silicate system (Sugita et al., 1997):

$xCa(OH)_2 + SiO_2 + nH_2O\ xCaO.\ SiO_2.\ nH_2O$

$$0.833 \leq X \leq 1.7$$

Pozzolanic material like fly ash utilize the Ca(OH)2 formed during hydration reaction of cement to form C-S-H gel, which improves many hardened properties.

Three methods for designing concrete with fly ash were identified by Munday, Ong, and Dhir (1983), namely the simple replacement approach, the modified replacement

method, and the rational method. Fly ash is substituted for an equivalent volume of cement in the simple replacement procedure, leaving the aggregate amounts unchanged. To obtain comparable 28-day strength with concrete prepared without fly ash, the modified replacement technique adds more fly ash weight than Portland cement weight. Washa & Withey (1953) were the ones who initially suggested this approach. Smith (1967) introduces the idea of cementing factor (k) to create a logical mechanism for fly ash inclusion in concrete. When evaluating the compressive strength of fly ash concrete, it is utilized to compute the equivalent to the mass of cement "kf" and to compute the effective water cement ratio w/(c+kf) ratio rather than w/c ratio.

Equations 2.2 and 2.3 from Murumi and Gupta (2015) illustrate how the efficiency factor dependent on fly ash % is represented using a power equation.

$$k_7 = 0.13(\%)^{-0.75} \qquad \text{Eq. 2.2}$$

$$k_{28} = 0.20(\%)^{-0.75} \qquad \text{Eq. 2.3}$$

2.2.4 Plasticizers

According to Anuj (2015), the weight of all powder ingredients, including cement and flash should be used to calculate the plasticizer dose. Supravin (2021) showed that admixture dose increases with increase in fly ash percentage. It was also shown that the dose decreases with increase in effective water to cement ratio.

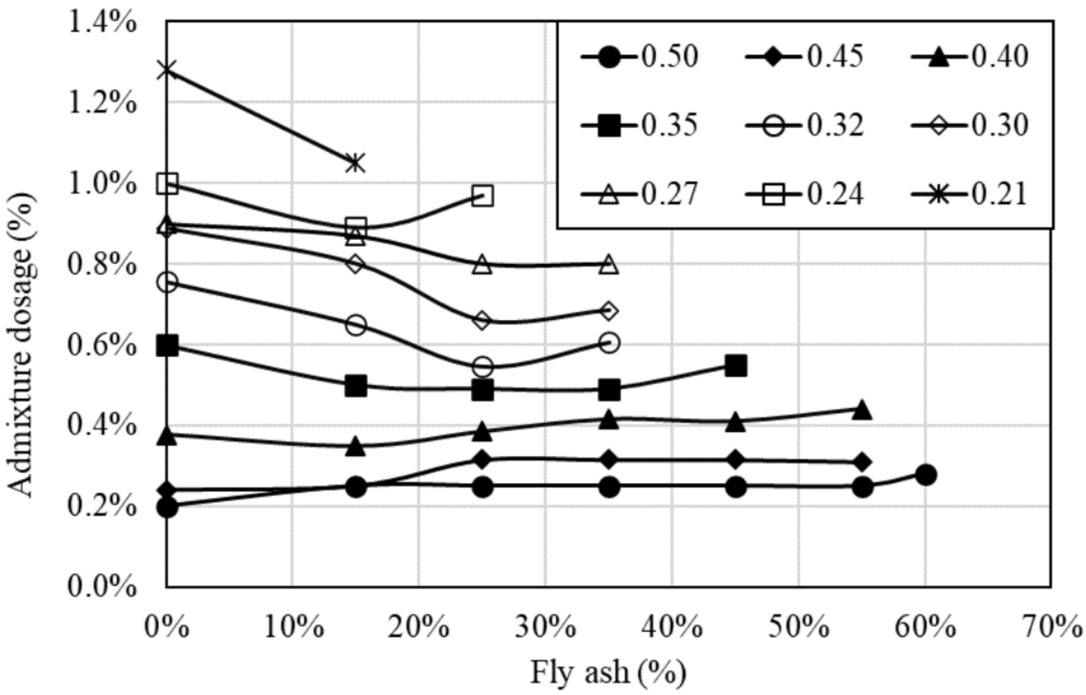

Figure 2.3: Percentage of admixture dosage vs Percentage of FA for different effective water/cement (Supravin, 2021)

2.2.5 Optimisation Experiments

For a design strength, once the k-factor and strength to effective w/c relationship are decided, the proportion of water, cement, and fly ash becomes fixed. One may change the quantity of water resulting in changes in the quantity of cement and fly ash. With the water change, admixture dosage will increase or decrease. An extremely dry mix might require a higher percentage of admixture. On the other hand, higher powder content might also make the mix excessively cohesive and require higher admixture. Hence, for any mix design with a fixed proportion of water to cementitious material (cement and fly ash), one may vary the water content and the plasticizer requirement may change. Looking into the workability and cost, one may find the optimum dosage of water. This will generally be in a range rather than a fixed point. Murumi (2016) had adopted four effective w/c = 0.55, 0.47, 0.39 and 0.31. Extensive optimization experiments were carried out and quantity of admixture dosage vs. fly ash percentage are presented for different effective water to cement ratios as shown in Fig. 2.11. It may be noted that the admixture required is a percentage of total powder content and remains fairly constant for each effective w/c and increases with the decrease of effective w/c.

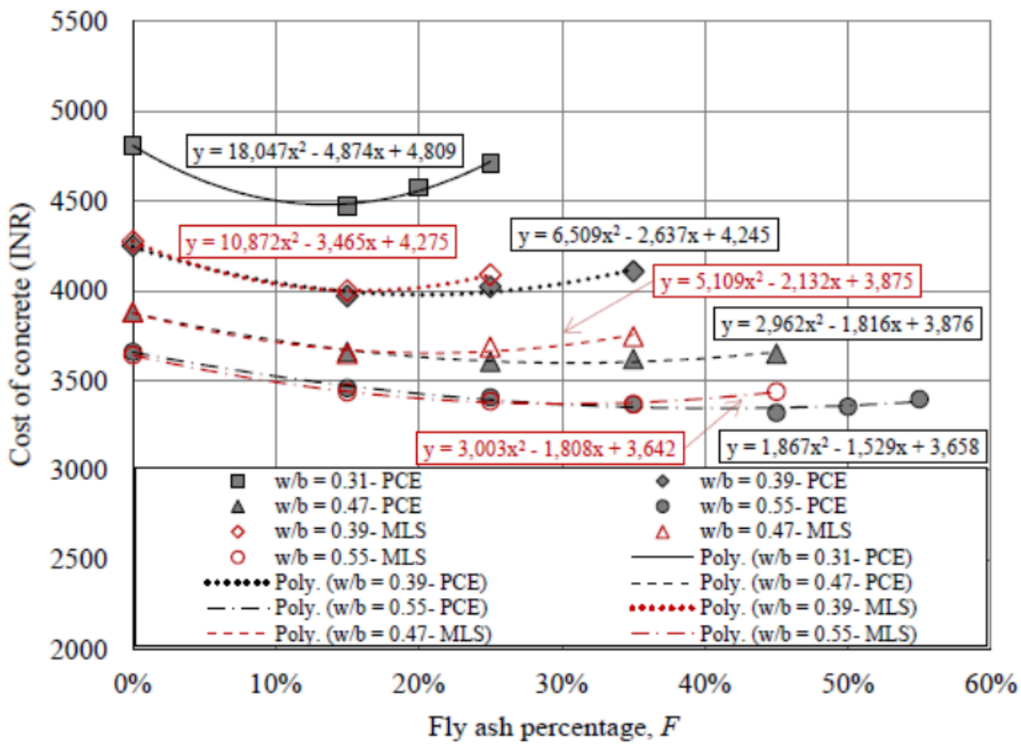

Fig. 2.4: Admixture content vs. fly ash % for best mixes in mix optimization (Murumi, 2016)

2.2.6 Compressive Strength

Different researchers reported different optimum percentage of flyash to get maximum compressive strength gai. Like Corinaldesi (2010) reported maximum strength with replacement of sand by 10% marble powder in mortar and concrete for same degree of workability. Likewise Hebhoub (2022), Vardhan (2019) and Tunc (2019) suggested 20%,40% and 10% respectively.

As it can be observed that the optimum proportion of marble powder and fly-ash varies in different literatures. Durán-Herrera et al (2011) showed that strength increased with time. Anuj

(2013) compared 28-days compressive strengths from various literatures and observed that compressive strength decreases with increase in water to cement ratio.

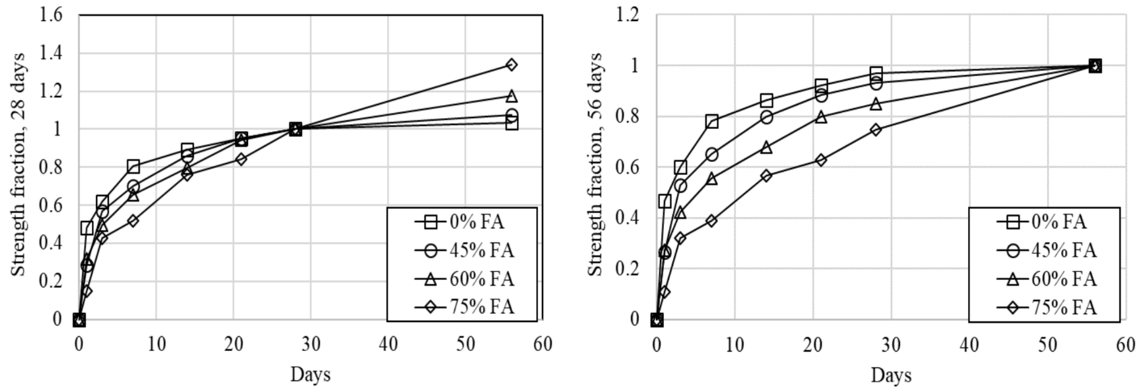

Figure 2.5: Strength development of concrete based on flyash percentage (Durran-Herrerra et al., 2011) by (Murumi, 2016)

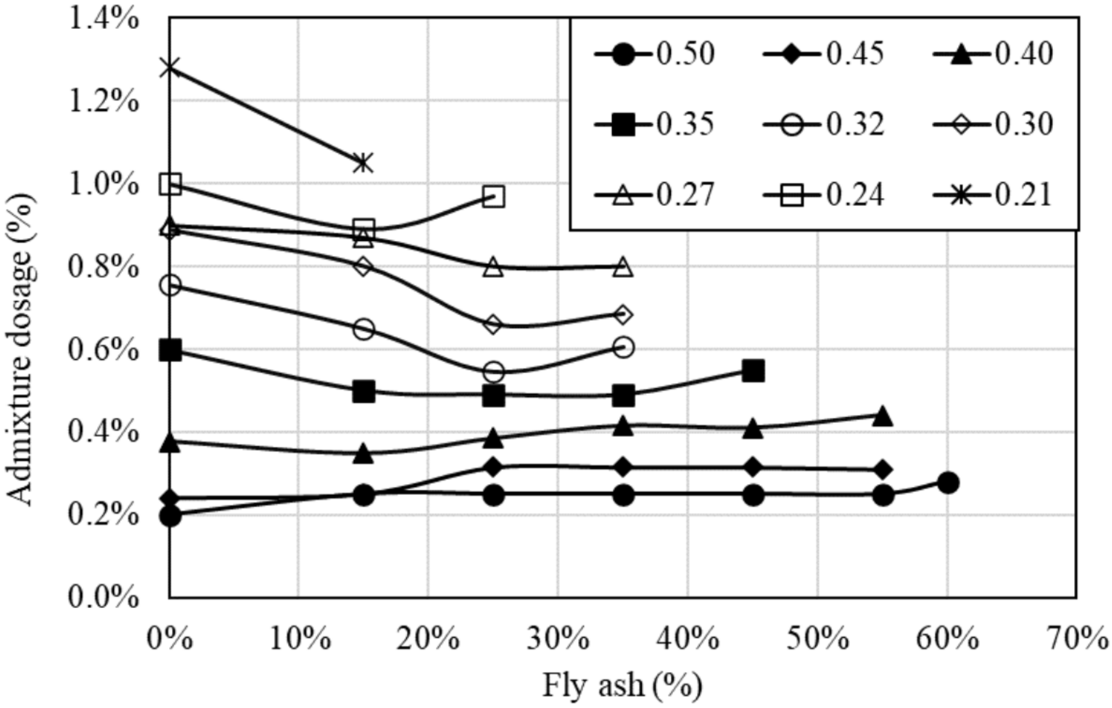

Figure 2.6: 28 Days Compressive strength tests vs w/b (Anuj 2013)

2.3 Effect of flyash on rheology and workability

Supravin (2021) showed that workability increased on addition of flyash. Hammat (2021) found that as the content of natural pozzolana increased in SCM, the viscosity and yield stress increased, resulting in reduced flowability and workability.

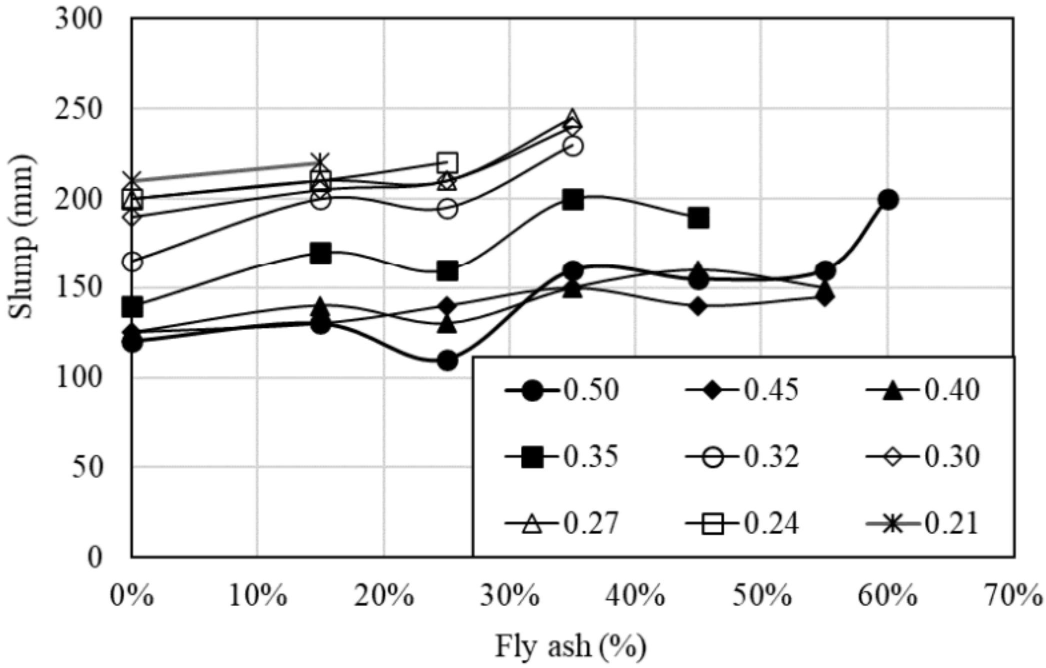

Figure 2.7: Slump vs %fly ash for different effective w/c (Supravin, 2021)

2.4 Materials

A study was conducted in which ordinary Portland cement which has a strength of 43 N was used as a binding material. Fine aggregate of size less than 1.18 mm which was extracted from the riverbed was used in the mix [11].

2.4.1 Admixtures

Waste from the rice mill plant boiler and sugar mill such as burnt rice husk ash and burnt bagasse ash were taken and used as filler and additives material [7]. The below figure 2.2 shows the particle size distribution of the materials used.

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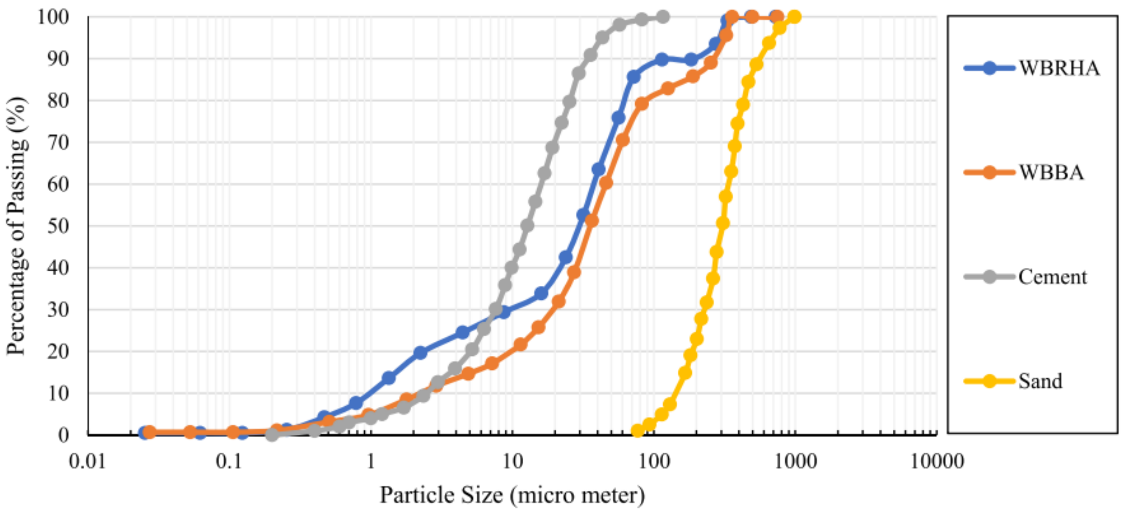

Figure 2.8: Particle Size distribution of raw materials

It was seen that by replacing the rice husk ash and bagasse ash up to 30% with the cement on the mortar mix shows that the strength of the mortar was in the standard range if the water absorption and alkaline acid resistance were kept adequate [7].

2.5 Properties of Fresh Mortar

Fresh mortar properties plays a vital role in the overall performance and durability of masonry structures. In order to achieve the desired strength, workability and consistency of the mortar, each property should be critically controlled and considered while mixing and applying the mortar. Several studies have been conducted which states the properties of fresh mortar.

2.5.1 Workability of mortar

Research shows that Bingam model can be adopted to study the behaviour of fresh mortar. The model states that the cement-based materials will be flowable when the shear stress of the mortar is higher than the yield stress. The shear rate of the mortar depends upon the stress and plastic viscosity of the mortar [5].

The yield stress of the mortar can be calculated by using the slump of the mortar. A study shows that slump test measures the total deformation of the cement-based materials under their own weight. Yield stress will be the half of the ratio of dead weight of cement paste to the area of paste spreaded after finding the slump of the mixture [12].

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter highlights the experimental methodology. Materials used are described in detail with their physical and chemical properties confirming to the Indian standards of practice in addition to that specimen preparation is discussed. In addition to this batching of materials in which mix design methodology, mixing operations and workability measurements are elaborated. Furthermore, different ways of application of mortar on the surfaces are discussed. Figure 3.1 shows the detailed methodology of this study.

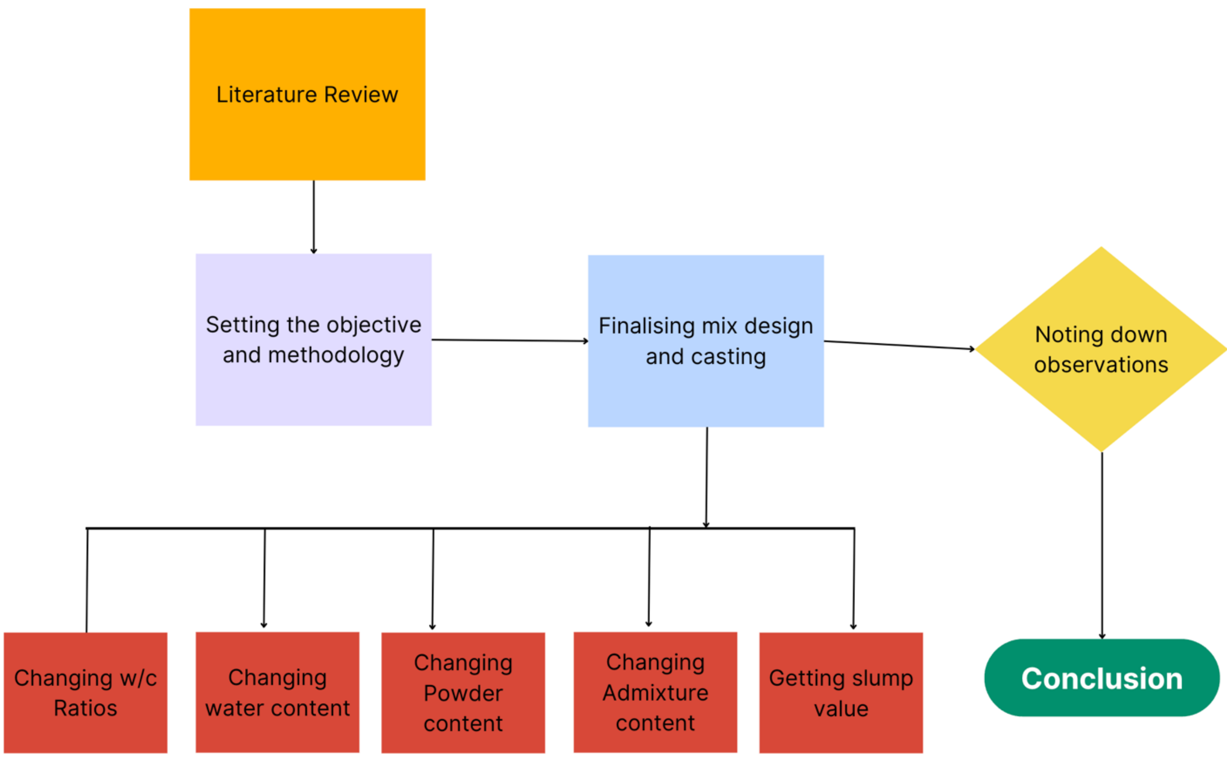

Figure 3.1: Methodology

3.2 Materials Used

The materials that are used in this research are Ordinary Portland Cement (OPC: 43 Grade), fly ash powder, natural sand as fine aggregates, water, and chemical admixture.

3.2.1 OPC Cement

Cement bags of OPC 43 grade were procured as specified to BIS: 8112-1989 in the form of 50kg bags and are stored in a moisture free environment until those are utilised. The specific gravity of the procured cement was 3.14. The below Table 3.1 highlights the comparison of physical and chemical properties of cement conforming to the specification mentioned in BIS: 8112-1989.

Table 3.1: Physical Properties of cement

S. No	Physical Properties	Results	As per IS 8112
1	Soundness		
	a. Le Chatelier expansion (mm)	1.0	10.0 (max)
	b. Autoclave expansion (mm)	0.04	0.80(max)
2	Blaine's fineness	290	225 (min)
3	Compressive strength, 28 days	56.3	43 (min); 58 (max)

Table 3.2: Chemical Properties of cement

S. No	Chemical Properties	Results	As per IS 8112
1.	(CaO– 0.7 SO_3) ÷ (2.8 SiO_2 + 1.2 Al_2O_3 + 0.65 Fe_2O_3)	0.88	0.66 (Min); 1.02(Max)
2.	Al_2O_3 ÷ Fe_2O	1.42	0.66(Min)
3.	Insoluble residue (% by mass)	1.95	3.0(Max)
4.	Magnesia (% by mass)	0.95	6.0 (Max)
5.	Total sulphur content calculated as sulphuric anhydride (SO3) (% by mass)	1.80	3.5 (Max.)
6.	Loss on ignition (% by mass)	1.82	5.0 (Max.)
7.	Total chlorides (% by mass)	0.01	0.10 (Max.)

3.2.2 Fly Ash Powder

Fly ash was obtained from Badarpur Thermal Power Station (BTPS) near Delhi, and was found to conform to IS 3812 (Part-1), 2013. The specific gravity of fly ash was found to be 2.10. Tables 3.3 and 3.4 show the comparison of test results of physical and chemical properties of fly ash with respect to requirements given in IS 3812 (Part-1) respectively.

Table 3.3 Physical Properties of Fly Ash

Sr. No.	Physical properties	Test result	Requirement as per IS 3812 (Part 1)
1	Blaine's fineness (m^2/kg)	343	320 (min.)
2	Particle retention on 45 µm sieve, wet sieving (% by mass)	29	34 (max.)
3	Lime reactivity (MPa)	5.1	4.5 (min.)
4	Compressive strength of neat cement mortar at 28 days (% of plain cement mortar cubes)	90.3	80 (min.)
5	Soundness by autoclave test (%)	0.08	0.8 (max.)

Table 3. 4 Chemical Properties of Fly Ash

Sr. No.	Chemical properties	Test result	Requirement as per IS 3812 (Part 1)
1	SiO_2+Al_2O_3+Fe_2O_3 (% by mass)	93.80	70 (min.)
2	SiO_2 (% by mass)	62.40	35 (min.)
3	Reactive silica (% by mass)	26.00	20 (min.)
4	MgO (% by mass)	0.70	5 (max.)
5	SO_3 (% by mass)	0.18	3 (max.)
6	Na_2O (% by mass)	0.21	1.5 (max.)

7	Cl (% by mass)	0.03	0.05 (max.)
8	CaO (% by mass)	1.90	10 (max. for siliceous and min. for calcareous)
9	Loss on ignition (% by mass)	1.30	5 (max.)

3.2.3 Fine Aggregate

Natural Sand as fine aggregate confirming to IS: 383-1970 were used. Seive analysis results of fine aggregate size as per IS 456:2000 and properties of fine aggregate are shown in tables below. The test results were obtained to confirm the requirements mentioned in IS:383-1970.

Table 3.5 Sieve analysis of fine aggregate (natural sand)

IS sieve size (mm)	Fine aggregate (natural sand)				
	Mass retained (g)	Percentage retained	Cumulative percentage retained	Cumulative percentage passing	Limits, Zone II (IS: 383)
10	0	0%	0%	100%	100
4.75	200	10%	10%	90%	90 to 100
2.36	240	12%	22%	78%	75 to 100
1.18	380	19%	41%	59%	55 to 90
0.600	280	14%	55%	45%	35 to 59
0.300	610	31%	86%	15%	8 to 30
0.150	173	9%	94%	6%	0 to 10
Pan	117	6%	100%	0%	–

Table 3.6: Properties of fine aggregate (natural sand).

Sr. No.	Property of natural sand	Test result	Limit in IS 383 for uncrushed fine aggregate
1	Gradation zone of IS 383	II	–
2	Bulk density (SSD), loose (kg/m^3)	1625	–
3	Bulk density (SSD), compacted (kg/m^3)	1806	–
4	Specific gravity	2.64	–
5	Water absorption (%)	1.40	–
6	Void at SSD (%)	31.6%	–
7	Silt and fine dust content (%)	4.3%	–
8	Deleterious materials (%)		
	(a) Coal and lignite	0.08	1.00 (max.)
	(b) Clay lumps	0.20	1.00 (max.)
	(c) Materials finer than 75 mm IS sieve	2.24	3.00 (max.)
	(d) Shale	0.01	1.00 (max.)
	(e) Sum of all total deleterious material (except mica)	2.53	5.00 (max.)

3.2.4 Water

Properties of water have been mentioned in the Table 3.7 Below

Table 3.7: Properties of water

Sr. No.	Parameter	Test result	Requirements of IS 456: 2000
1	Volume of 0.02 normal NaOH to neutralize 100 ml sample of water, using phenolphthalein as an indicator, ml	Nil	5 ml (Max.)
2	Volume of 0.02 normal H_2SO_4 to neutralize 100 ml sample of water, using phenolphthalein as an indicator, ml	13.5	5 ml (Max.)
3	Solid content		
	(a) Organic	82	200 (Max.)
	(b) Inorganic	368	3000 (Max.)
	(c) Sulphates (as SO3)	65.28	400 (Max.)
	(d) Chloride (as Cl)	114.47	2000 - plain concrete; 500 - reinforced concrete (Max)
	(e) Suspended matter	2	2000 (Max.)
4	pH	7.4	6 (Min.)

3.2.5 Chemical Admixture

From lingo sulphonate to Poly Carboxylic Ether (PCE) beta naphthalene sulphonate base, water reducers have evolved significantly. Initially water reduction capacity was around 5-7% which later increased 15-20% using beta naphthalene sulphonate base and melamine sulphonate base, PCE further improved it to 25 - 30%. In this project Master Glenium SKY 8233 from M/s BASF India Lad, was used for all types of concrete castings. It is a PCE based admixture, light brown in color with a pH ≥ 6 and a specific gravity of 1.08 ± 0.01 at 25°C. It was used to maintain the slump of the concrete around 130mm.

3.3 Specimen Preparation

3.3.1 Preparation for fine aggregate

A conical frustum was used to bring fine aggregate to SSD condition as specified by ASTM C 128-01, 2001. Appropriate moisture correction was done for fine aggregates for each batch of mix. The figure 3.1 shows the instrument used to calculate the saturated surface dry condition of fine aggregate.

Figure 3.2: SSD Instrument for sand

3.4 Batching of materials

All the constituents of mortar (cement, SCM, fine aggregate, water and chemical admixtures) were batched by mass on a weighing scale. The accuracy of the weighing scale used was ±0.01 g and ±0.05 kg for chemical admixtures and all other materials respectively.

3.4.1 Mix Design

The mix design of the controlled mortar is started first by assuming the percentage of fly ash and quantity of water content for per cubic meter. Using percentage of fly ash to be added in the mix, K-factor is calculated which shows the efficiency of fly as a binder material. K-factor is calculated by using the equation 1 shown below.

$$\boldsymbol{k = 0.162 \times F\%^{-0.854}} \quad \text{Eq...(1)}$$

Where F is the percentage of flyash to be added

After evaluating the K-factor water/cement ratio is fixed in that using equation 2 and 3 quantity of cement and fly ash are evaluated.

$$\boldsymbol{B} = \boldsymbol{c} + \boldsymbol{kf} \text{ Eq...(2)}$$

$$\boldsymbol{F}\% = \frac{\boldsymbol{f}}{\boldsymbol{c}+\boldsymbol{f}} \text{ Eq...(3)}$$

Where B is the binder content and can be found W/C ratio where C can be written as $c + kf$, c and f are the quantity of cement and fly ash per meter cube of mortar.

Further, to calculate the quantity of sand equation 4 is used as shown below

$$990 = Wt.of\ water + \frac{Wt.of\ Cement}{Sp.Gravity\ of\ Cement} + \frac{Wt.of\ Flyash}{Sp.Gravity\ of\ F.A} + \frac{Wt.of\ Sand}{Sp.Gravity\ of\ sand} \text{ Eq...(4)}$$

Where 990 represents the total volume of mortar including 1% of voids in the mixture using the above equation quantity if sand is evaluated.

3.4.2 Mixing of Mortar

IS 2250 was followed for mixing the mortar. Sand is first dry mixed with cement and flyash using a mechanical mixture of quantity 0.07m3 for a duration of 30 seconds. Followed by which water has been added to the dry mixture and mixing was done for 1 minute to get he uniform mix. Thereafter chemical admixture was added in different phases to satisfy the workability for spraying and hand plastering.

3.4.3 Measuring workability

The workability of the prepared mix was measure by using the slump come of dimensions 150mm height, 50mm and 100mm being the diameter of top and bottom end of the slump cone as it is the half of the dimensions of the slump cone for measing the concrete as shown in the figure 3.2 below. The mortar was poured in the cone in three layers and each layer was compacted using tamping rod. Tamping was done 12 times to each layer as the dimensions were half of the standard cone number of tamps are also half as compared to the standard tamping operation for the concrete.

Figure 3.3: Slump cone for mortar

3.5 Application of Mortar on the masonry surfaces

Each mortar mix prepared were tested to be applied on the brick masonry walls by means of hand applications and by spray application. The operation was performed to identify that which mix design can be sprayed easily and which can be applied by means of hand on the surfaces.

3.5.1 Hand Application

The prepared mix was first applied on the brick masonry by using trowel. The mix was applied by the mason in a generally applied manner and the slump value was recorded.

3.5.2 Spray Application

Admixture was added in the mix design which was applied by hand hence the workability of the mortar was increased. Compressed air was used to spray the mortar on the brick masonry and then the surface was finished by using the float or trowel. The slump was recorded from each mix design which was applicable to be applied on the surfaces.

3.6 Chapter Summary

This chapter discussed the experimental methodology followed in this study. Materials utilised with there physical and chemical properties confirming to IS codes, specimen preparation and materials batching with the mix design methodology was elaborated in detail. Additionally, methodology involved for measuring the workability and applications of mortar on the surfaces by means of different methods were also highlighted.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter highlights the mix design matrix adopted, Workability results are discussed in which effect of admixture on slump, admixture demand at different water content are elaborated in detail. In addition, effect on slump at different water content are discussed. Furthermore admixture demand at different fly ash dosages are elaborated in detail.

4.2 Mix Details

Initial Design mix matrix was created as shown in table 4.1 below. The table shows the different design mix that were tested. In these four different W/C ratios were adopted from literature review initially the water is assumed to be 235 Kg/ m^3 for all the W/C and also powder content is also kept the same i.e., 500 Kg/ m^3 to achieve this fly ash content was increased as shown in below table. Later the water content was increased to 255 Kg/ $m^{3.}$ Which also effects the total powder content. Similarly, further the water content was increased to 275 Kg/ m^3. The workability and applicability of these mixes on walls by means of hand and spray were tested. The results are explained later in this chapter.

Table 4.1: Mix design Matrix with Id

Mix Id	W/C Ratio	Total Powder (Kg/m^3)	Water (Kg/ m^3)	Cement (Kg/m^3)	Fly Ash %	F.A (Kg/m^3)	Sand (Kg/m^3)
ZH A1	0.480	490	235	490	0%	0	1559
ZH A2	0.480	501	235	432	14%	69	1526
ZH A3	0.540	500	235	373	26%	127	1506
ZH A4	0.600	500	235	330	34%	169	1491
ZH A5	0.700	500	235	276	45%	224	1471
ZH B1	0.480	531	255	531	0%	0	1472
ZH B2	0.480	543	255	469	14%	74	1437
ZH B3	0.540	543	255	404	26%	139	1415
ZH B4	0.600	543	255	359	34%	184	1399
ZH B5	0.700	543	255	300	45%	243	1378
ZH C1	0.480	573	275	573	0%	0	1386
ZH C2	0.480	585	275	505	14%	80	1348
ZH C3	0.540	585	275	436	26%	149	1324
ZH C4	0.600	585	275	387	34%	198	1307

ZH C5	0.700	585	275	323	45%	262	1284

4.3 Workability Results

In the present experimental study, applicability of different mixes has been studied for different mixes as discussed in above table 4.1. Table 4.2 highlights the workability results of the design mixes discussed above.

Table 4.2: Workability results of the design mixes

W/C Ratio	Water (Kg/m^3)	Fly Ash %	Total Powder (Kg/m^3)	Add Mix (%)	Slump (mm)	Hand	Spray
0.480	235	0%	490	0.4	0	Yes	No
0.480	235	0%	490	0.6	40	Yes	Yes
0.480	255	0%	531	0.4	35	Yes	Yes
0.480	255	0%	531	0.55	80	No	Yes
0.480	275	0%	573	0.25	35	Yes	Yes
0.480	275	0%	573	0.4	93	No	Yes
0.480	235	14%	501	0.4	25	Yes	No
0.480	235	14%	501	0.6	80	No	Yes
0.480	255	14%	543	0.35	30	Yes	Yes
0.480	255	14%	543	0.5	80	No	Yes
0.480	275	14%	585	0.3	40	Yes	Yes
0.480	275	14%	585	0.4	85	No	Yes
0.540	235	26%	500	0.8	50	Yes	Yes
0.540	235	26%	500	0.9	80	No	Yes
0.540	255	26%	543	0.5	25	Yes	No
0.540	255	26%	543	0.6	75	Yes	Yes
0.540	275	26%	585	0.2	45	Yes	Yes
0.540	275	26%	585	0.3	85	No	Yes
0.600	235	34%	499	0.5	30	Yes	No
0.600	235	34%	499	0.7	70	Yes	Yes
0.600	255	34%	543	0.3	32	Yes	No
0.600	255	34%	543	0.4	85	No	Yes
0.600	275	34%	585	0.2	33	Yes	No
0.600	275	34%	585	0.3	85	No	Yes
0.700	235	45%	500	0.6	30	Yes	No
0.700	235	45%	500	0.7	70	Yes	Yes
0.700	255	45%	543	0.4	40	Yes	Yes
0.700	255	45%	543	0.5	80	No	Yes
0.700	275	45%	585	0.2	27	Yes	No

0.700	275	45%	585	0.3	75	Yes	Yes

The above table shows that in addition of the admixture to the mixes it increases the workability in terms of slump it was further noted that the mix to be applied on the wall by means of hand the slump range should be between 0 mm to 50mm, If the slump ranges above 50mm the workability was high with which it was not Significant to work with these mixes using trowel. On the other hand, for applying mortar by means of spray it was found that the slump should be above 30 to 35mm. The upper limit was 85 to 90mm. above which the mortar was flowable, and it was seen that after applying the mortar gets flow down through the wall. At slump 30 to 35mm the mix was sprayable, but the workability required to spray was not significant, hence it is recommended for spraying the slump should be above 50 mm. The above table 4.2 shows the mix design which can significantly applied on the masonry surface by hand and spray.

4.3.1 Effect of Admixture on Slump

It was seen that as admixture increases the slump of the mixture increases the below figures 4.1 and 4.2 shows the effect of admixture on the slump of the mixture. Further it was seen that increasing the admixture after 80 to 95mm of slump in the mixture the mix was becoming more flowable, and which is not significant enough to be applied on the wall surfaces as after applying the mix was flowing off the surface.

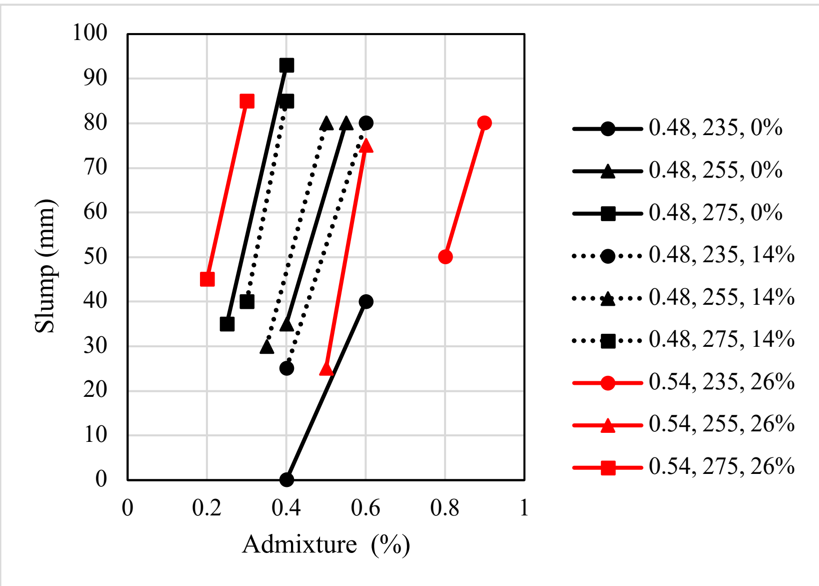

Figure 4.1: Effect of admixture on Slump (0.48 and 0.54 W/C)

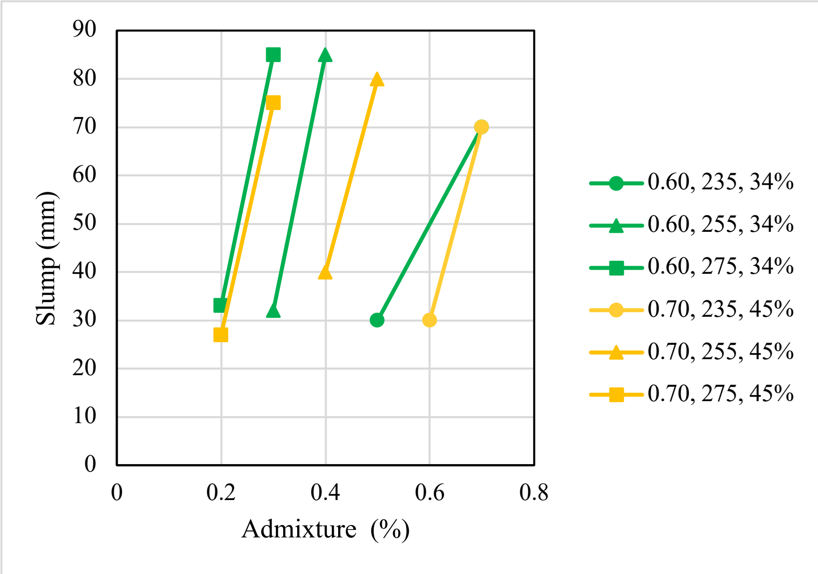

Figure 4.2: Effect of admixture on Slump (0.6 and 0.7 W/C)

4.3.2 Admixture Usage at different Water Content

The below figure 4.3 shows the admixture dosage required at different water contents at lower slump. Lower slump is the mark where the mortar mixes get significant enough to be applied on the masonry surfaces. It was seen that at lower water content at 235Kg/m^3 the admixture dosage ranges from 0.4 to 0.8% of the total powder content at different w/c ratios and different percentages of fly ash content. Similarly for 255 Kg/m^3 ^{the} dosage ranges from 0.3 to 0.5% further, for 275 Kg/m^3 of water content the admixture dosage is 0.2 to 0.3%.

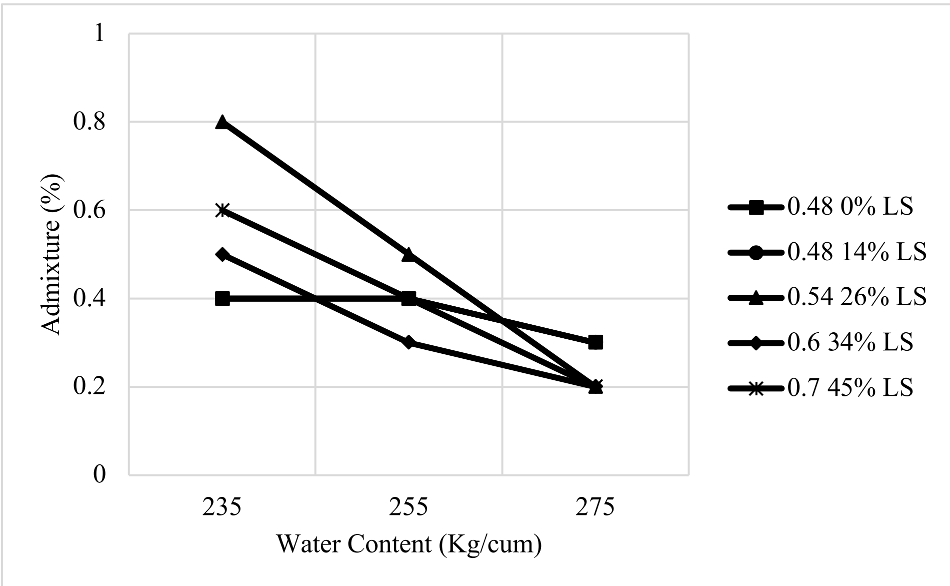

Figure 4.3: Admixture dosage at different water contents at lower slump

The below figure 4.4 shows the admixture dosage required at different water contents at higher slump. higher slump is the mark where the mortar mixes gets significant enough to be applied on the masonry surfaces above this slump the mixes are not very significant enough to be applied on the surfaces. It was seen that at lower water content at 235Kg/m^3 the admixture dosage ranges from 0.6 to 0.9% of the total powder content at different w/c ratios and different percentages of fly ash content. Similarly for 255 Kg/m$^{3 \text{ the}}$ dosage ranges from 0.4 to 0.6% further, for 275 Kg/m^3 of water content the admixture dosage is 0.3 to 0.4%.

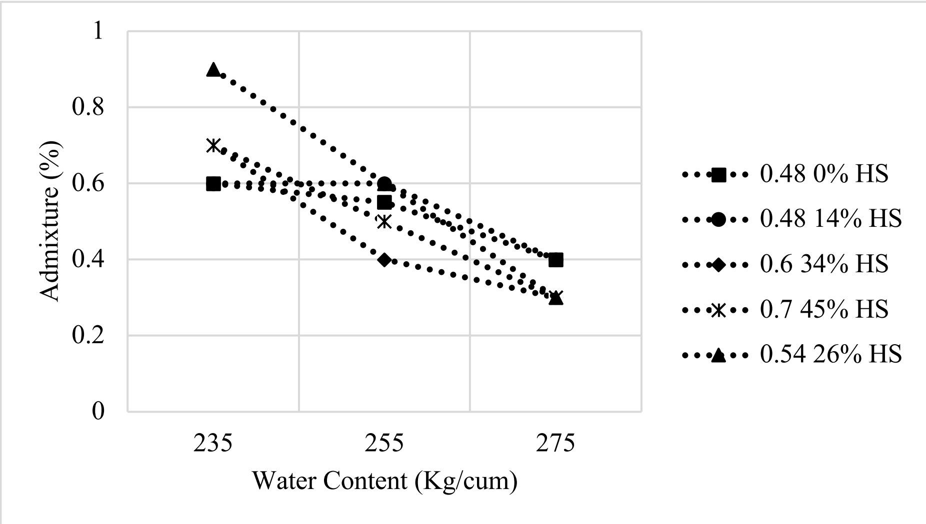

Figure 4.4: Admixture dosage at different water contents at Higher slump

4.3.3 Effect on slump at different water content

It can be stated from the results that as the water content increases the slump of the mortar mixes also increases which says that water content is directly proportional to the slump of the mixes. It was found that at lower water content to achieve high slump values use of admixture is necessary the dosage of admixture to achieve the required slump values are discussed in the previous section. It was found that the optimised water content to be adopted is 255 Kg/m^3 at which optimum admixture dosage is required. Furthermore, at 255Kg/m^3 different fly ash percentages were tested which are discussed in below sections.

4.3.4 Admixture requirement at different Fly ash %

To Study the relationship between the admixture requirement at different percentages of fly ash content, 0.48 w/c ratio was taken at 255 Kg/m^3 of water content and fly ash content was increased from 0 to 45%. It was found that to achieve 80mm slump the admixture demand is decreasing as increasing the fly ash content up to 35% after which the demand of admixture starts increasing in the mortar mixes. In previous studies (Meera 2020) It was stated that in concrete the demand of admixture gets decreased up to 15% of fly ash usage there after the demand of admixture start increasing. In the case of mortar as shown in figure 4.5 it was found that the demand for admixture gets decreased up to 35% of fly ash content.

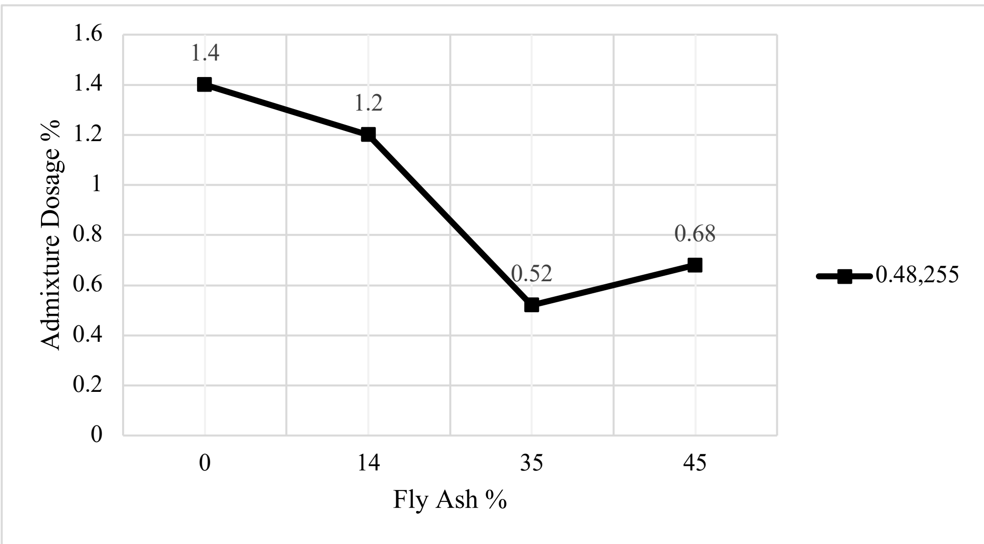

Figure 4.5: Admixture dosage vs Fly ash Content at constant slump

Similarly, in other case to verify the results admixture dosage was kept constant and slump was recorded at different fly ash content. Figure 4.6 shows the relation between the slump and fly ash content in which admixture dosage was kept constant, In this regard it was seen that slump starts increasing up to 35% of fly ash content there after it starts to decrease.

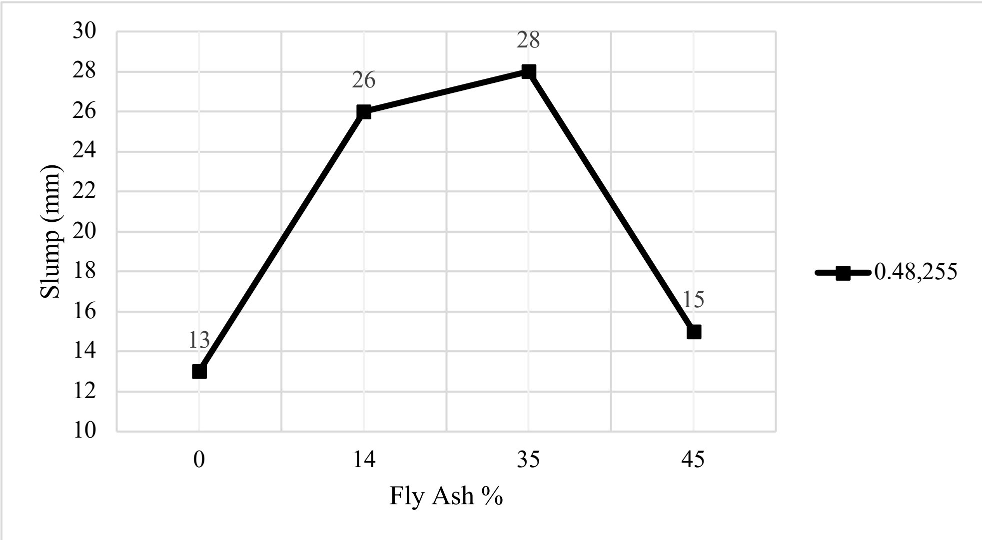

Figure 4.6: Slump vs Fly ash Content at constant Admixture dosage

4.4 Chapter Summary

In this chapter mix design details were discussed and their workability results are elaborated in which effect on slump at different and mixture dosages were highlighted and the admixture usage at different water contents are discussed. In addition, effect on slump at different water content was discussed. Lastly Admixture requirement at different fly ash content was discussed.

CHAPTER 5

CONCLUSION

5.1 Key Findings:

- This study systematically investigated the mix design factors for the application of mortar on brick surfaces, specifically focusing on hand and spray applications. The K-factor theory was employed as a framework for analysis and evaluation.
- The investigation of different water-to-cement ratios and levels of fly ash content yielded valuable observations regarding the workability of the mortar mixtures.
- The slumps seen in hand applications exhibited a range of 0 mm to 50-60mm, however in spray applications, they displayed a wider variation of 30mm to 85-90mm. This disparity underscores the distinctive attributes associated with each application method.
- The findings of this study highlight a notable correlation between the dosage of admixture and the content of fly ash. Specifically, it was noted that there exists an inverse link between these two factors. This relationship is evident up to a fly ash content of 35%, after which there is a subsequent drop in the observed correlation. These results underscore the importance of achieving a delicate equilibrium in order to attain optimal cohesivity and adhesiveness in the material being studied.
- The results of this study enhance our comprehension of the behaviour of mortar when subjected to various application methods. This knowledge may be utilized to make educated judgments regarding mix design in the field of masonry construction.
- This study provides a fundamental basis for future research and improvement of mortar compositions, providing valuable insights for customizing mixtures to meet individual project needs and application methods in the field of civil engineering.

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