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# STUDIES ON HIGH PERFORMANCE MORTAR MIXES (Part II SHRINKAGE AND SORPTIVITY CHARACTERISTICS)

**Kumar P.R* Seshu D.R** and Rao C.B.K*****

*An Experimental investigation was done to study the effect of silica fume and superplasticizer in rich mortar mixes(1:1, 1:1.15, 1:1.2) using different grades of cement for use in high performance ferrocement works. In this part of the experimental program the Shrinkage and Sorptivity characteristics, which play an important role in durability of ferrocement, have been studied. It was concluded from the investigation that the addition of silica fume and superplasticizer in slag cement, improves the performance characteristics of mortar. The results of these characteristics at the end of 3, 7 and 28days of curing are presented. The rich mortar mixes with enhanced properties are termed as High Performance Mortars (HPM).*

## INTRODUCTION

The significance of the studies on cement mortar need not be emphasized as the cement mortar is a structural material in many applications such as production of ferrocement elements, repair of deteriorated RCC structures, and strengthening of structural components using jacketing techniques[1]. Improving the performance aspects of cement mortar significantly enhances the durability properties in many applications of cement concrete. One of the means of achieving High Performance is by the use of pozzolanic admixtures as silica fume. With the use of the mineral admixtures, along with the superplasticizers, better benefits can be achieved. The pore structure can be modified with the use of these mineral and chemical admixtures and is very important for performance requirements in terms of flow, strength, shrinkage and sorptivity. It is known that if the water-cement ratio is carefully controlled the pore structure can be modified and there by the shrinkage and sorptivity can be greatly reduced. The silica fume and superplasticizers have a great role in this process to play as the matrix in ferrocement has much larger and pronounced influence on the behavior of final product[2].

Shrinkage is caused by the loss of water by evaporation, hydration of cement and also by carbonation. During hydration process a change in volume occurs due to the reduction in volume of cement paste. When the mortars/concretes are stressed and exposed to unsaturated air, they get dried and in that process water will be drawn from the mortar/concrete resulting in drying shrinkage. Sorptivity is a material property which characterizes the tendency of a porous material to absorb and transmit water by capillarity. Both these properties Viz Shrinkage and Sorptivity are closely related to the modification of pore structure and there by have an influencing effect on the durability properties of mortar mixes by way of Performance. The performance of ferrocement can be improved by increasing both strength and durability of mortar mixes. Such high strength mortar mixes with improved properties performance characteristics can be termed as High Performance Mortar(HPM).Extensive studies are

* Lecturer in Civil Engineering, National Institute of Technology, Warangal-506 004, A.P, India.
** Assistant Professor of Civil Engineering, National Institute of Technology, Warangal-506 004, A.P, India.
*** Professor of Civil Engineering, National Institute of Technology, Warangal-506 004, A.P, India.

conducted to explore the behavior of High Performance Mortar mixes. In this Part-II of the work, the shrinkage and sorptivity aspects are studied. In Part-I of the investigation Strength and Flow characteristics are already reported[3].

## EXPERIMENTAL INVESTIGATION

Three mixes 1:1/0.34, 1: 1.15/0.35 & 1:1.2/0.37 were selected from the earlier studies conducted on compressive strength and flow characteristics of High Performance Mortars[3]. The parameters in the investigation include the strength of cement(varied by changing the grade of cement), dosage of silica fume and the dosage of superplasticizer. Silica fume was used as a partial replacement with dosage varying from 0, 5, 10, 15, 20% by weight of cement. From the previous investigations[3-4]the optimum dosage of silica fume was fixed as 10%. The study on the performance aspects Viz: shrinkage and sorptivity are studied on the selected mortar mixes. A comparison is made for all the four conditions i.e.; with /without silica fume and/or with and without superplasticizer.

### Materials

- **Cement**: Three grades of cement 53, 43 grade OPC and slag cement were used. These were according to IS: 12269-Code of Practice confirming to 53 Grade Ordinary Portland Cement[5], IS:8112-Code of Practice confirming to 43 Grade Ordinary Portland Cement[6] and IS:455-Code of Practice confirming to Slag Cement[7] respectively, with specific gravities 3.12,3.15 and 3.161.
- **Sand**: Locally available river sand confirming to IS: 650-Code of Practice confirming to Standard Sand for Testing of Cement[8], passing through sieve size of 1.10 mm was used. The Fineness modulus of sand was 2.4 and specific gravity was 2.44.
- **Water**: Potable water was used for mixing and curing purpose.
- **Silica fume**: The mineral admixture was obtained from a near by Ferro Silicon Alloy Industry. The silica content was about 92% and the lime reactivity 2.34. The compressive strength was 14.35 N/mm$^2$. The initial and final setting times were 40 minutes and 143 minutes respectively. The specific gravity was 1.84 and the fineness by wet sieving was 5.04%.
- **Superplasticizer**: Sulphonated Naphthalene condensate (SNF) was used as a superplasticizer for the present study. The specific gravity of SNF was 1.18 and at 25°C it has a good compatibility with Portland and slag cements.

### Casting and Testing

A total of 108 prisms of 25.4 X 25.4 mm size and 282 mm length were cast to determine the drying shrinkage of the mortar mixes adopted. The casting and testing was done as per IS- 4031 Part-10- Code of Practice for determining Drying Shrinkage[9]. The length of three specimens was measured using the length comparator to the nearest 0.01 percent at the end of 3, 7 and 28 days of curing. The difference in the initial length and the length at the specified period of curing was reported as the drying shrinkage.

A total of 108 cubes were cast and tested for the sorptivity. The sorptivity value was determined by measuring the capillary rise absorption rate using water as a test fluid. The test procedure was done as per Hall's method[10]. The quantity of absorbed fluid in a time period of 30 minutes was measured by weighing the specimen for assessing the sorptivity.

## INTERPRETATION AND DISCUSSION OF TEST RESULTS

The results obtained from the experimental investigations are tabulated in Tables 1 and 2. From the results obtained the effects of with/without and/or with/without superplasticizers on the shrinkage and sorptivity was analyzed.

**Table 1 28-Day Compressive strength and Flow values for variation in silica fume content**

| STAGE | GRADE | MIX | INITIAL LENGTH (mm) | SHRINKAGE STRAIN(X $10^{-6}$) | | |
|---|---|---|---|---|---|---|
| | | | | 3 DAY | 7DAY | 28DAY |
| I | 43 GRADE | 1:1.00/0.34 | 282.20 | 412.0 | 520.0 | 616.0 |
| | | 1:1.15/0.35 | 276.30 | 417.0 | 546.0 | 627.0 |
| | | 1:1.20/0.37 | 275.40 | 447.0 | 562.0 | 697.0 |
| | 53 GRADE | 1:1.00/0.34 | 283.16 | 402.0 | 501.0 | 593.0 |
| | | 1:1.15/0.35 | 286.22 | 400.0 | 512.0 | 592.0 |
| | | 1:1.20/0.37 | 283.44 | 480.0 | 512.0 | 620.0 |
| | SLAG CEMENT | 1:1.00/0.34 | 283.10 | 380.0 | 463.0 | 560.0 |
| | | 1:1.15/0.35 | 283.17 | 350.0 | 401.0 | 483.0 |
| | | 1:1.20/0.37 | 284.45 | 392.0 | 447.0 | 582.0 |
| II | 43 GRADE | 1:1.00/0.34 | 281.62 | 392.0 | 484.0 | 524.0 |
| | | 1:1.15/0.35 | 282.42 | 417.0 | 492.0 | 536.0 |
| | | 1:1.20/0.37 | 291.46 | 440.0 | 560.0 | 603.0 |
| | 53 GRADE | 1:1.00/0.34 | 282.64 | 376.0 | 407.0 | 444.0 |
| | | 1:1.15/0.35 | 283.64 | 401.0 | 443.0 | 516.0 |
| | | 1:1.20/0.37 | 291.72 | 421.0 | 502.0 | 572.0 |
| | SLAG CEMENT | 1:1.00/0.34 | 281.15 | 340.0 | 362.0 | 402.0 |
| | | 1:1.15/0.35 | 291.72 | 375.0 | 401.0 | 487.0 |
| | | 1:1.20/0.37 | 287.62 | 384.0 | 406.0 | 421.0 |
| III | 43 GRADE | 1:1.00/0.34 | 282.60 | 375.0 | 492.0 | 520.0 |
| | | 1:1.15/0.35 | 282.46 | 382.0 | 503.0 | 541.0 |
| | | 1:1.20/0.37 | 274.63 | 391.0 | 497.0 | 555.0 |
| | 53 GRADE | 1:1.00/0.34 | 282.46 | 345.0 | 443.0 | 502.0 |
| | | 1:1.15/0.35 | 283.42 | 320.0 | 413.0 | 448.0 |
| | | 1:1.20/0.37 | 275.42 | 340.0 | 381.0 | 488.0 |
| | SLAG CEMENT | 1:1.00/0.34 | 283.16 | 260.0 | 302.0 | 397.0 |
| | | 1:1.15/0.35 | 265.43 | 240.0 | 270.0 | 316.0 |
| | | 1:1.20/0.37 | 283.66 | 284.0 | 340.0 | 384.0 |
| IV | 43 GRADE | 1:1.00/0.34 | 283.16 | 302.0 | 385.0 | 476.0 |
| | | 1:1.15/0.35 | 283.62 | 312.0 | 374.0 | 484.0 |
| | | 1:1.20/0.37 | 282.65 | 384.0 | 438.0 | 487.0 |
| | 53 GRADE | 1:1.00/0.34 | 283.64 | 292.0 | 302.0 | 397.0 |
| | | 1:1.15/0.35 | 275.45 | 302.0 | 372.0 | 440.0 |
| | | 1:1.20/0.37 | 276.42 | 301.0 | 344.0 | 386.0 |
| | SLAG CEMENT | 1:1.00/0.34 | 283.65 | 201.0 | 222.0 | 246.0 |
| | | 1:1.15/0.35 | 290.46 | 272.0 | 297.0 | 351.0 |
| | | 1:1.20/0.37 | 283.42 | 214.0 | 257.0 | 267.0 |

STAGES

- I — without superplasticizer and without silica fume
- II — with superplasticizer and without silica fume
- III — without superplasticizer and with silica fume
- IV — with superplasticizer and with silica fume

## Table 2 Sorptivity values for cement mortars

| STAGE | GRADE | MIX | WATER ABSORBED(gms) | | | SORPTIVITY(mm/ √(min)) | | |
|---|---|---|---|---|---|---|---|---|
| | | | 3DAY | 7DAY | 28DAY | 3DAY | 7DAY | 28DAY |
| I | 43 GRADE | 1:1.00/0.34 | 6.13 | 5.86 | 5.08 | 0.570 | 0.545 | 0.472 |
| | | 1:1.15/0.35 | 6.67 | 6.35 | 5.27 | 0.620 | 0.590 | 0.490 |
| | | 1:1.20/0.37 | 7.31 | 6.88 | 6.56 | 0.680 | 0.640 | 0.610 |
| | 53 GRADE | 1:1.00/0.34 | 5.72 | 5.51 | 5.00 | 0.532 | 0.512 | 0.465 |
| | | 1:1.15/0.35 | 6.33 | 5.81 | 5.08 | 0.589 | 0.540 | 0.472 |
| | | 1:1.20/0.37 | 5.27 | 5.05 | 4.95 | 0.490 | 0.470 | 0.360 |
| | SLAG CEMENT | 1:1.00/0.34 | 5.48 | 4.97 | 3.48 | 0.510 | 0.462 | 0.324 |
| | | 1:1.15/0.35 | 6.07 | 5.59 | 4.95 | 0.564 | 0.520 | 0.460 |
| | | 1:1.20/0.37 | 5.16 | 4.62 | 4.52 | 0.480 | 0.430 | 0.420 |
| II | 43 GRADE | 1:1.00/0.34 | 5.81 | 5.59 | 4.41 | 0.540 | 0.520 | 0.410 |
| | | 1:1.15/0.35 | 6.24 | 6.04 | 4.95 | 0.580 | 0.562 | 0.460 |
| | | 1:1.20/0.37 | 7.10 | 6.78 | 6.26 | 0.660 | 0.630 | 0.582 |
| | 53 GRADE | 1:1.00/0.34 | 4.32 | 4.11 | 3.76 | 0.402 | 0.382 | 0.350 |
| | | 1:1.15/0.35 | 6.04 | 5.53 | 4.86 | 0.562 | 0.514 | 0.452 |
| | | 1:1.20/0.37 | 6.35 | 5.81 | 5.48 | 0.590 | 0.540 | 0.510 |
| | SLAG CEMENT | 1:1.00/0.34 | 3.50 | 3.33 | 2.80 | 0.325 | 0.310 | 0.260 |
| | | 1:1.15/0.35 | 5.81 | 5.29 | 4.43 | 0.540 | 0.492 | 0.412 |
| | | 1:1.20/0.37 | 5.81 | 5.48 | 5.27 | 0.540 | 0.510 | 0.490 |
| III | 43 GRADE | 1:1.00/0.34 | 5.51 | 5.21 | 4.22 | 0.512 | 0.484 | 0.392 |
| | | 1:1.15/0.35 | 5.83 | 5.29 | 4.48 | 0.542 | 0.492 | 0.417 |
| | | 1:1.20/0.37 | 6.23 | 6.24 | 5.81 | 0.580 | 0.540 | 0.520 |
| | 53 GRADE | 1:1.00/0.34 | 4.60 | 4.53 | 4.16 | 0.428 | 0.421 | 0.387 |
| | | 1:1.15/0.35 | 5.51 | 4.45 | 4.11 | 0.512 | 0.414 | 0.382 |
| | | 1:1.20/0.37 | 4.52 | 4.41 | 4.30 | 0.420 | 0.410 | 0.400 |
| | SLAG CEMENT | 1:1.00/0.34 | 4.25 | 3.93 | 3.07 | 0.395 | 0.365 | 0.285 |
| | | 1:1.15/0.35 | 5.18 | 4.84 | 3.89 | 0.482 | 0.450 | 0.362 |
| | | 1:1.20/0.37 | 4.62 | 4.25 | 4.08 | 0.430 | 0.395 | 0.380 |
| IV | 43 GRADE | 1:1.00/0.34 | 5.16 | 4.68 | 4.03 | 0.480 | 0.435 | 0.375 |
| | | 1:1.15/0.35 | 5.51 | 5.05 | 4.14 | 0.512 | 0.470 | 0.385 |
| | | 1:1.20/0.37 | 6.35 | 5.51 | 5.22 | 0.590 | 0.512 | 0.485 |
| | 53 GRADE | 1:1.00/0.34 | 3.81 | 3.68 | 3.50 | 0.354 | 0.342 | 0.325 |
| | | 1:1.15/0.35 | 5.22 | 4.78 | 3.68 | 0.485 | 0.444 | 0.342 |
| | | 1:1.20/0.37 | 5.83 | 4.62 | 4.53 | 0.542 | 0.430 | 0.421 |
| | SLAG CEMENT | 1:1.00/0.34 | 2.85 | 2.60 | 2.58 | 0.265 | 0.242 | 0.240 |
| | | 1:1.15/0.35 | 4.89 | 4.43 | 3.03 | 0.455 | 0.412 | 0.282 |
| | | 1:1.20/0.37 | 5.17 | 4.22 | 4.41 | 0.481 | 0.392 | 0.400 |

Sorptivity $s = I / t^{1/2}$ where "s" is sorptivity in mm/√(min) " t " is the elapsed time in minutes and $I = \Delta W/A.d$, where $\Delta W$= increase in weight A= surface area of specimen through which water penetrates and d=density of water.

**STAGES**

I — without Superplasticizer and without silica fume
II — with Superplasticizer and without silica fume
III — without Superplasticizer and with silica fume
IV — with Superplasticizer and with silica fume

## Study on the Effect of grade of cement and age on Shrinkage

Table 1 shows the details of the test results of the shrinkage strain measured for the four stages. The plots for the variation are shown in Figs. 1, 2, 3, and 4 respectively. From the table and figures, it can be noted that for all the three mixes and three grades of cement the drying shrinkage strains have increased with age. It can also be observed that as the grade of cement increased (i.e.: as the strength of cement is increased), the shrinkage strains have decreased for identical mixes. For mortars using slag cement the drying shrinkage strains were minimum amongst the three mixes.

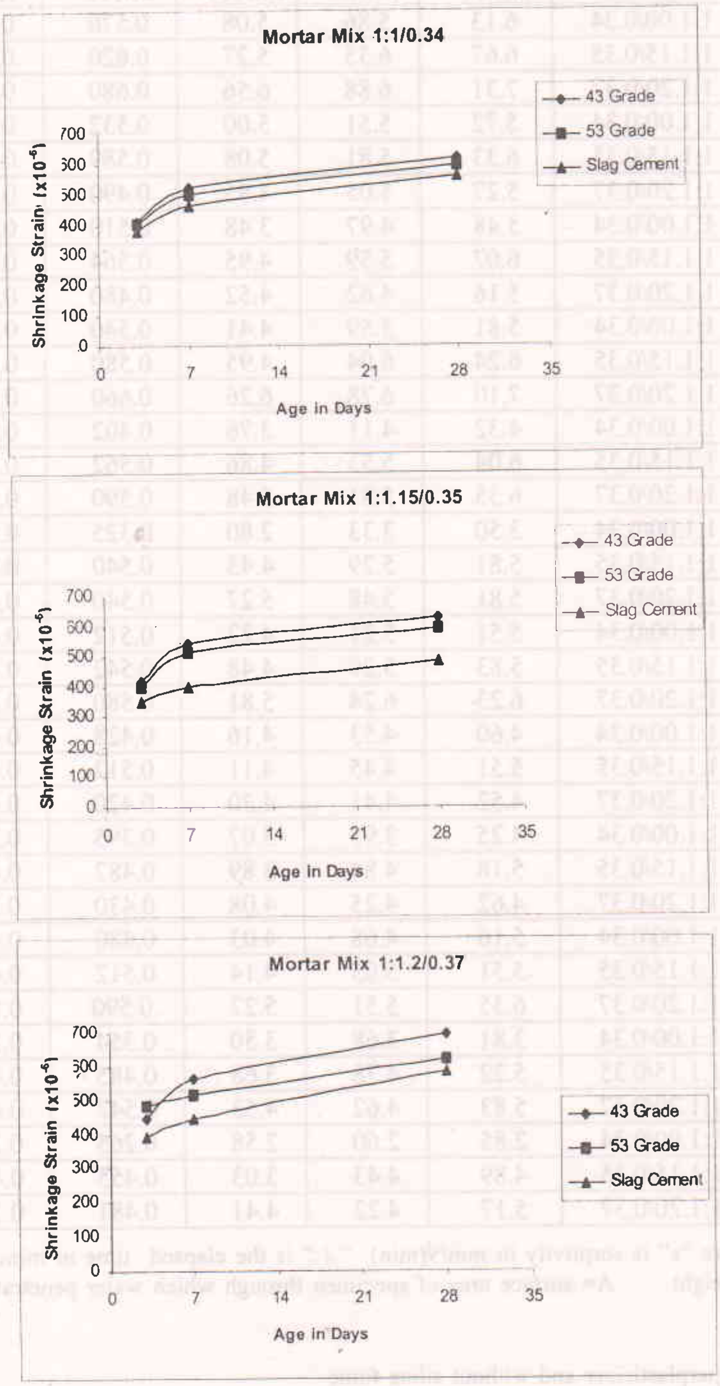


**Fig. 1. Age Vs Shrinkage Strain ( Stage -1)**

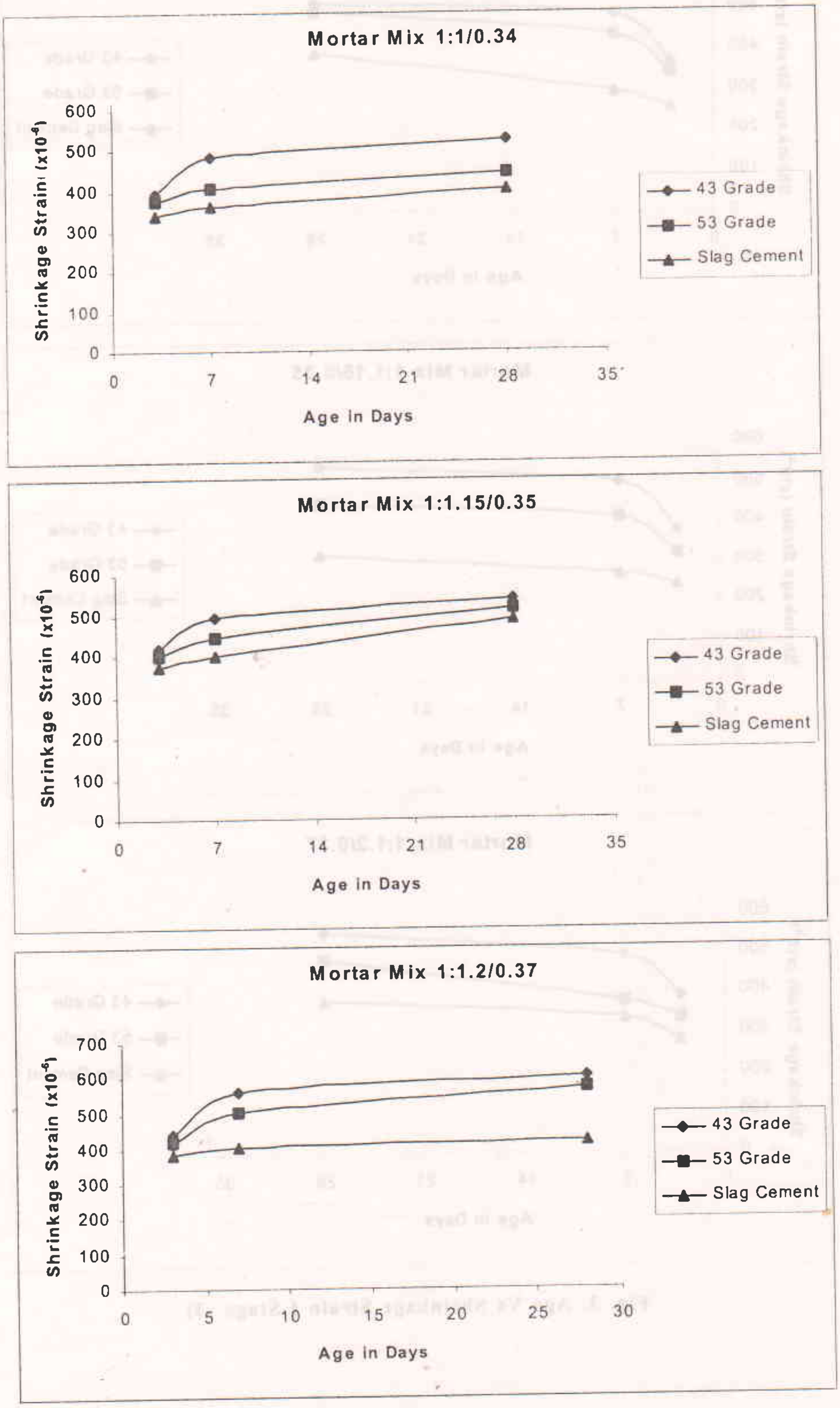


**Fig. 2. Age Vs Shrinkage Strain ( Stage -2)**

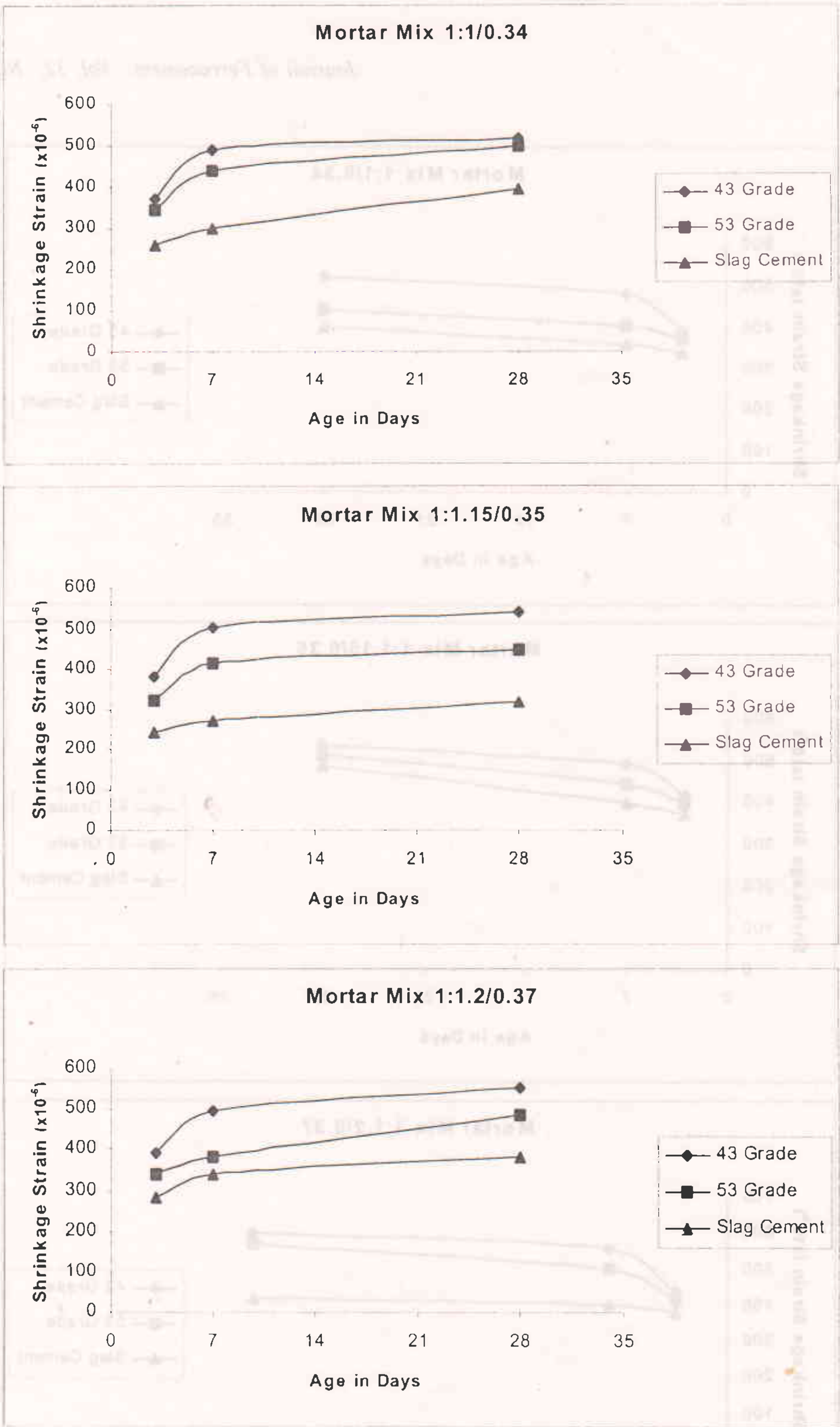


Fig. 3. Age Vs Shrinkage Strain ( Stage -3)

## Effect of addition of superplasticizer on Shrinkage

From Table 1 and Fig. 5, it can be noticed that in general the addition of superplasticizer has decreased the shrinkage strain for all the three grades of cement and for all the three mixes. The effect of superplasticizers in decreasing the shrinkage strains is more pronounced in slag cement mortar mixes.

## Effect of Silica Fume replacement on Shrinkage

From Table 1 and Fig. 6, it can be observed that the partial replacement of cement with 10% silica fume decreased the shrinkage for all the three grades of cement and for all the three mixes. However, the decrease is more in cement mortars with slag cement compared to cement mortars using 43 grade cement.

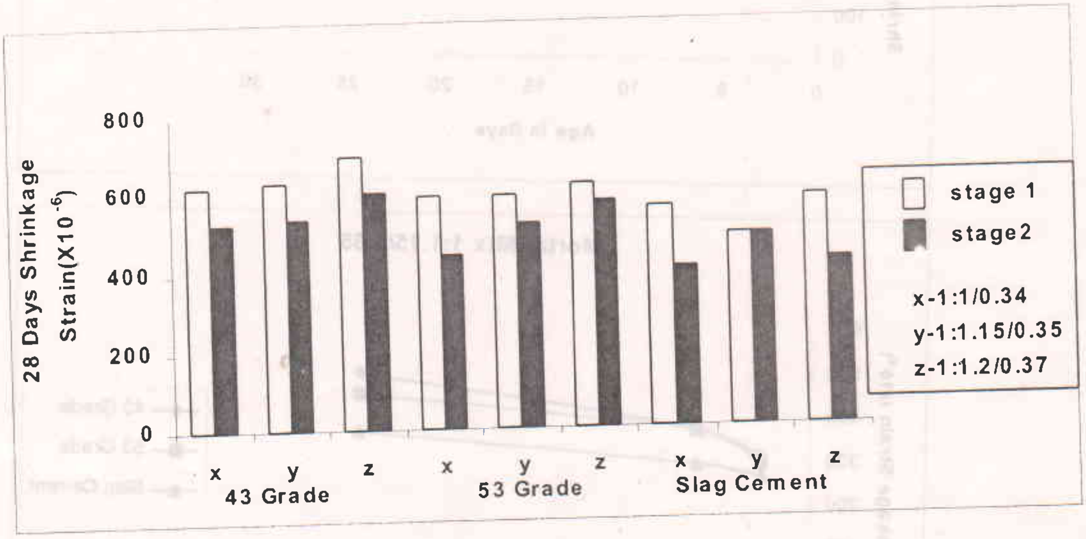


Fig. 5. Effect of SuperPlasticizer on Shrinkage of Mortar

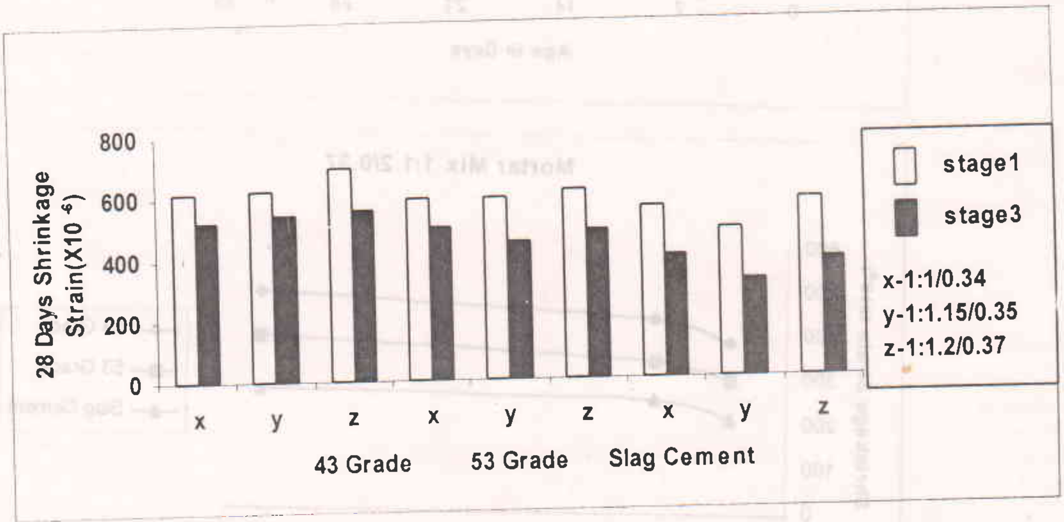


Fig. 6. Effect of Silica Fume on Shrinkage of Mortar

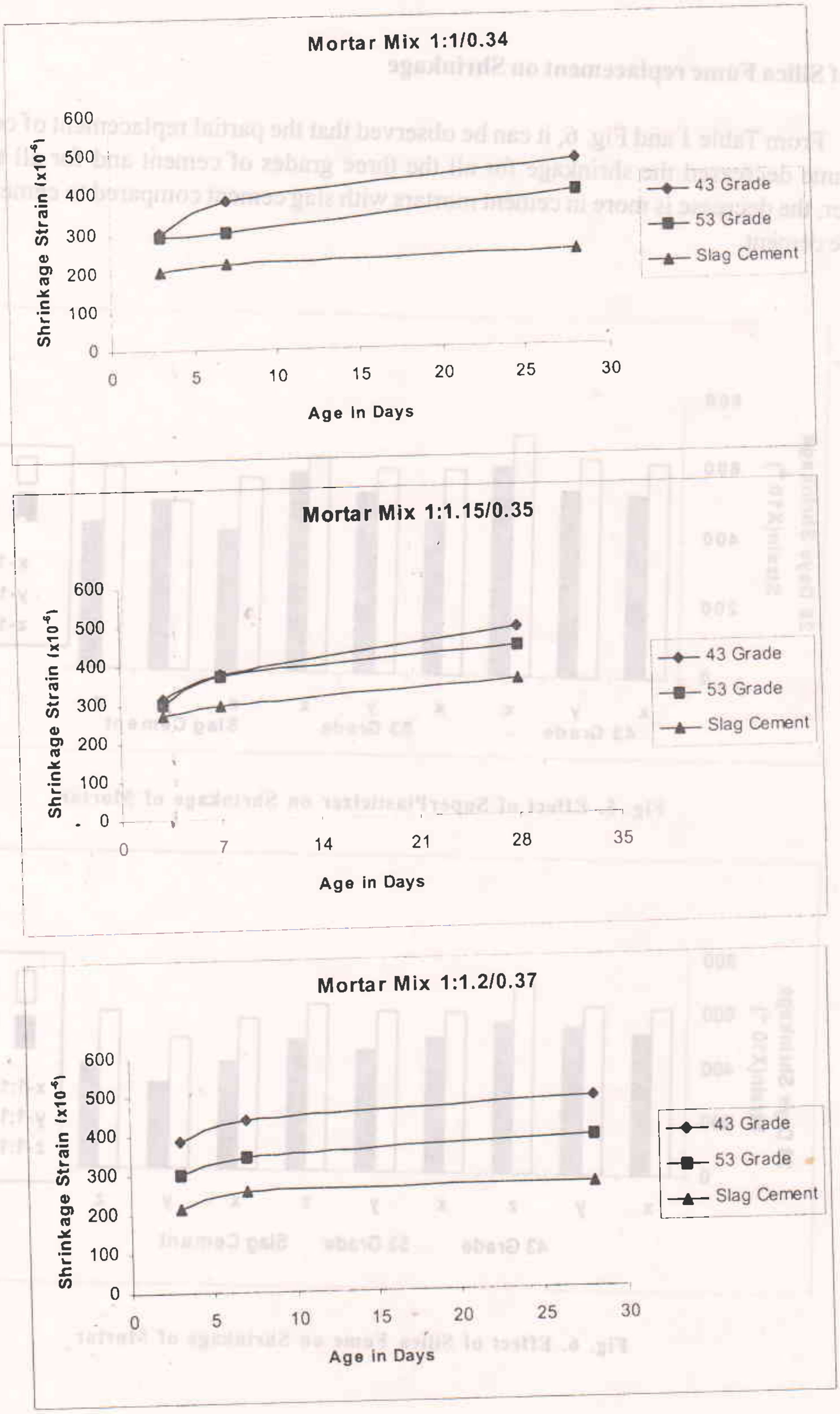


**Fig. 4. Age Vs Shrinkage Strain ( Stage -4)**

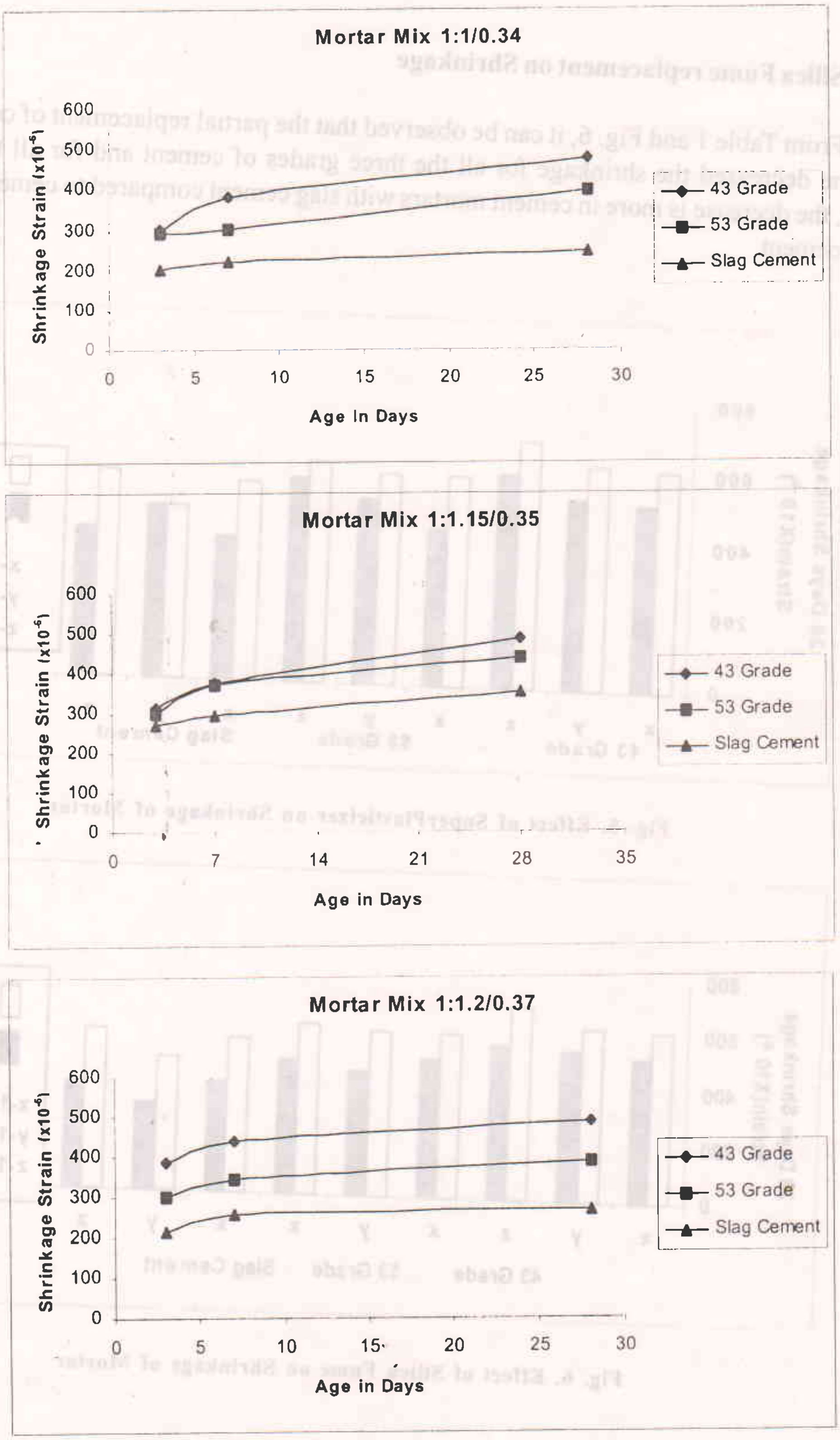


Fig. 4. Age Vs Shrinkage Strain ( Stage -4)

## Effect of addition of superplasticizer on Shrinkage

From Table 1 and Fig. 5, it can be noticed that in general the addition of superplasticizer has decreased the shrinkage strain for all the three grades of cement and for all the three mixes. The effect of superplasticizers in decreasing the shrinkage strains is more pronounced in slag cement mortar mixes.

## Effect of Silica Fume replacement on Shrinkage

From Table 1 and Fig. 6, it can be observed that the partial replacement of cement with 10% silica fume decreased the shrinkage for all the three grades of cement and for all the three mixes. However, the decrease is more in cement mortars with slag cement compared to cement mortars using 43 grade cement.

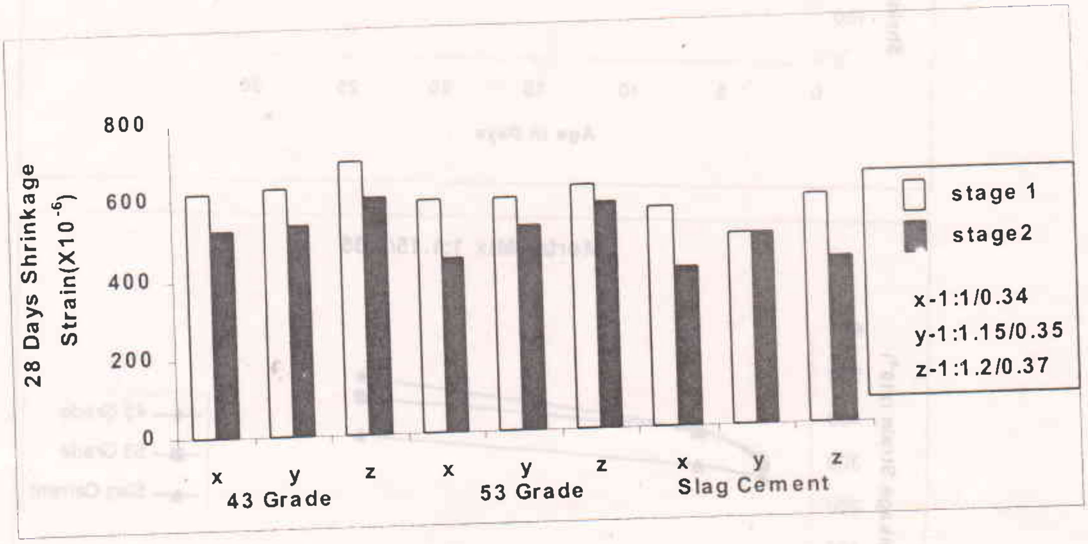


Fig. 5. Effect of SuperPlasticizer on Shrinkage of Mortar

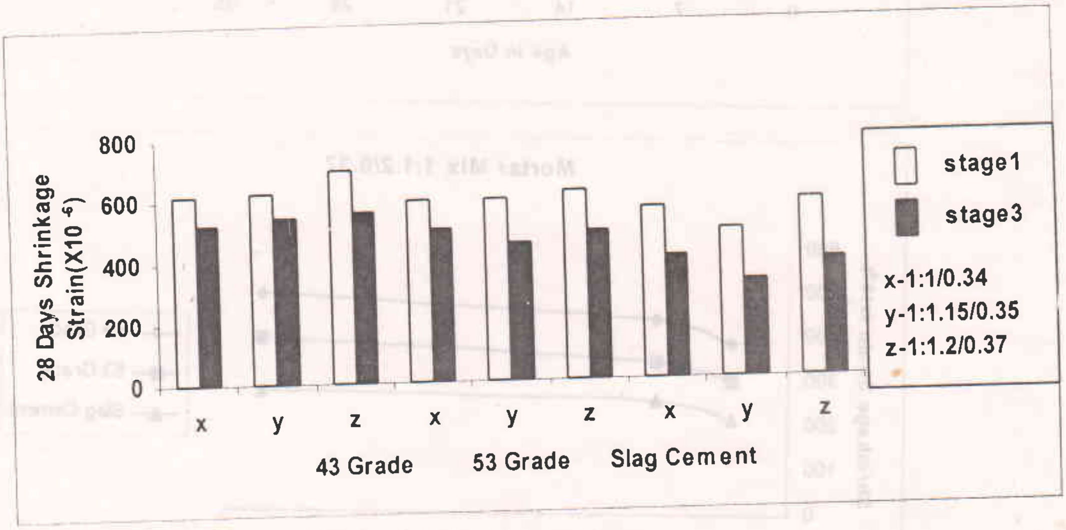


Fig. 6. Effect of Silica Fume on Shrinkage of Mortar

**Combined effect of Silica Fume and superplasticizer on Shrinkage**

Table 1 and Fig. 7 show the combined effect of silica fume and superplasticizer on the drying shrinkage of cement mortar. It can be observed that in all the three grades of cement and for all the three mixes, the drying shrinkage strain decreased. The average percentage decrease in drying shrinkage in slag cement mortars was 45.8% as compared to 32%, 25.2% in 53 grade cement and 43 Grade cement respectively. The maximum percentage decrease in drying shrinkage was 56% in case of the cement mortar mix 1:1/0.34, prepared using slag cement. This indicates that the rich mortar mixes are more sensitive to the addition of silica fume and have shown more decrease in the drying shrinkage.

**Effect of age and grade of cement on Water Sorptivity**

The results of the sorptivity values obtained for all four stages are shown in Table 2 and plotted in Figs. 8, 9, 10 and 11 respectively. There is a general decrease in sorptivity for mortars with/without silica fume and with/without superplasticizer dosage, with an increase in age and the grade of cement. Slag cements gave a better performance from the point of view of sorptivity for all the three mix proportions.

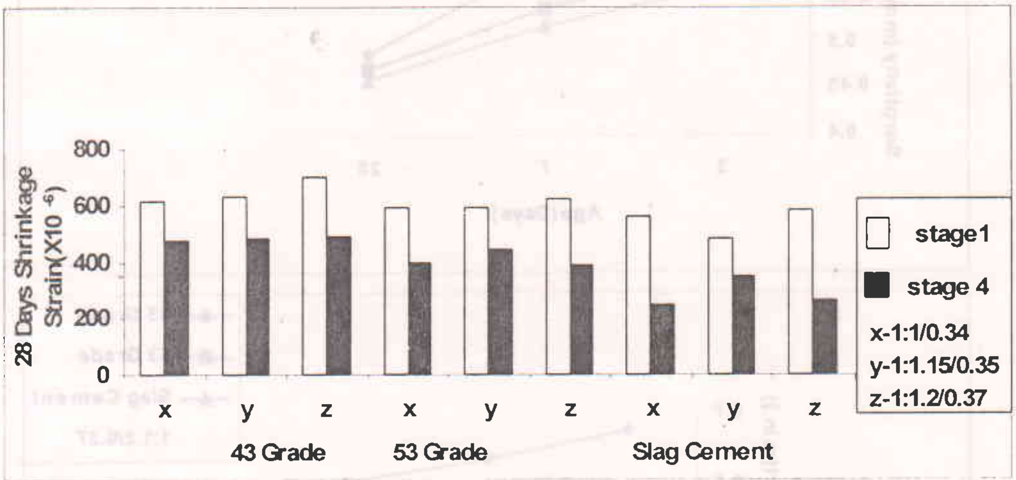


Fig. 7. Effect of SuperPlasticizer &Silica Fume on Shrinkage of Mortar

**Effect of superplasticizer addition on Water Sorptivity**

From Table 2 and Fig. 12, it can be noted that there is a marginal decrease in sorptivity with the addition of superplasticizer, for all the grades of cement and for all the three mixes. A sorptivity value of 0.26 mm/sqrt (min) for mix 1:1/0.34 using slag cement was obtained as against 0.41 mm/sqrt(min) for the 1:1/0.34 mix using 43-grade cement. The observation leads to the conclusion that the mortar mixes prepared with slag cement may consist of more number of discontinuous pores as compared to other cements.

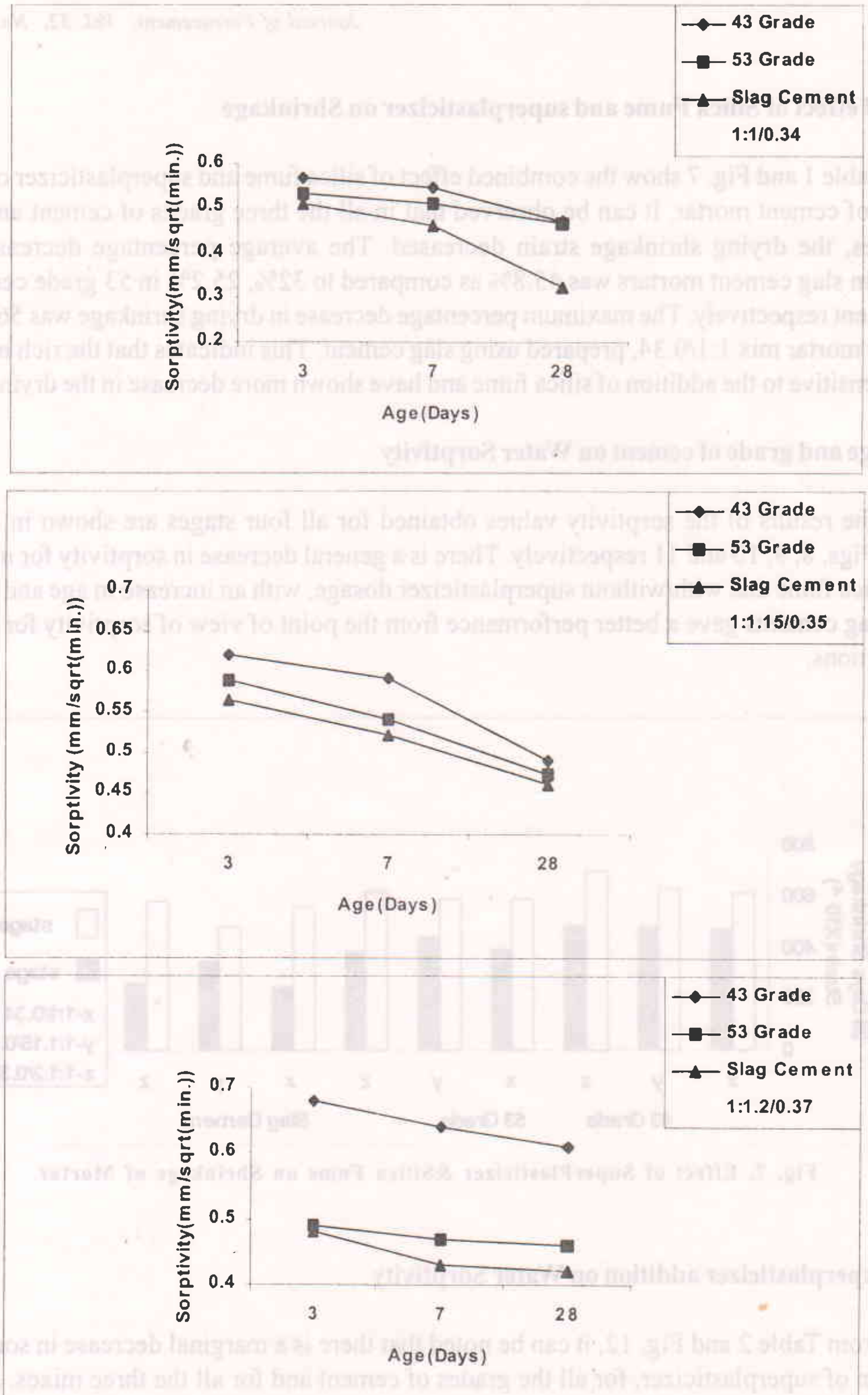


**Fig. 8. Sorptivity Vs Age (Stage 1- Without Silica Fume and Superplasticizer)**

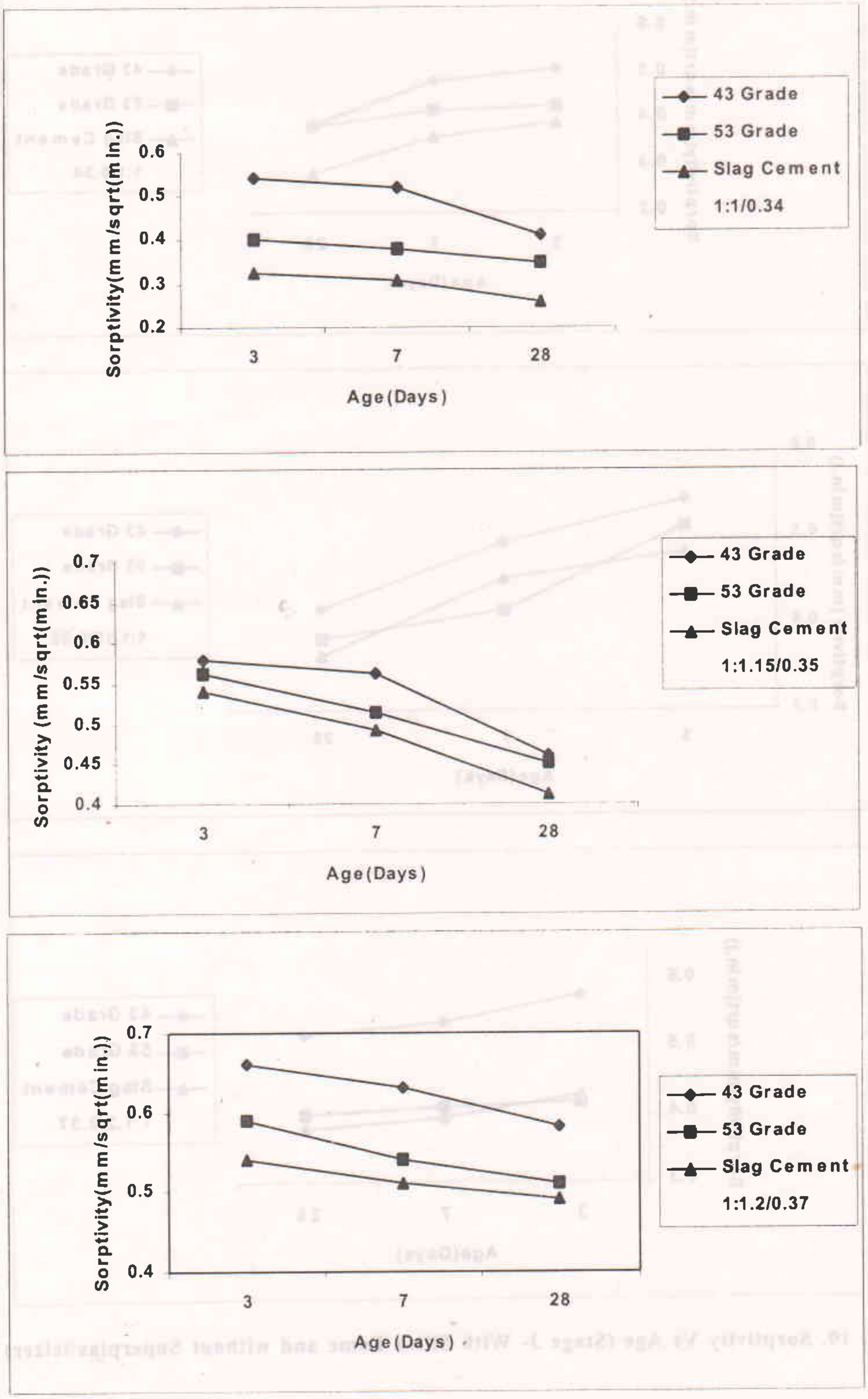


**Fig. 9. Sorptivity Vs Age (Stage 2- Without Silica Fume and with Superplasticizer)**

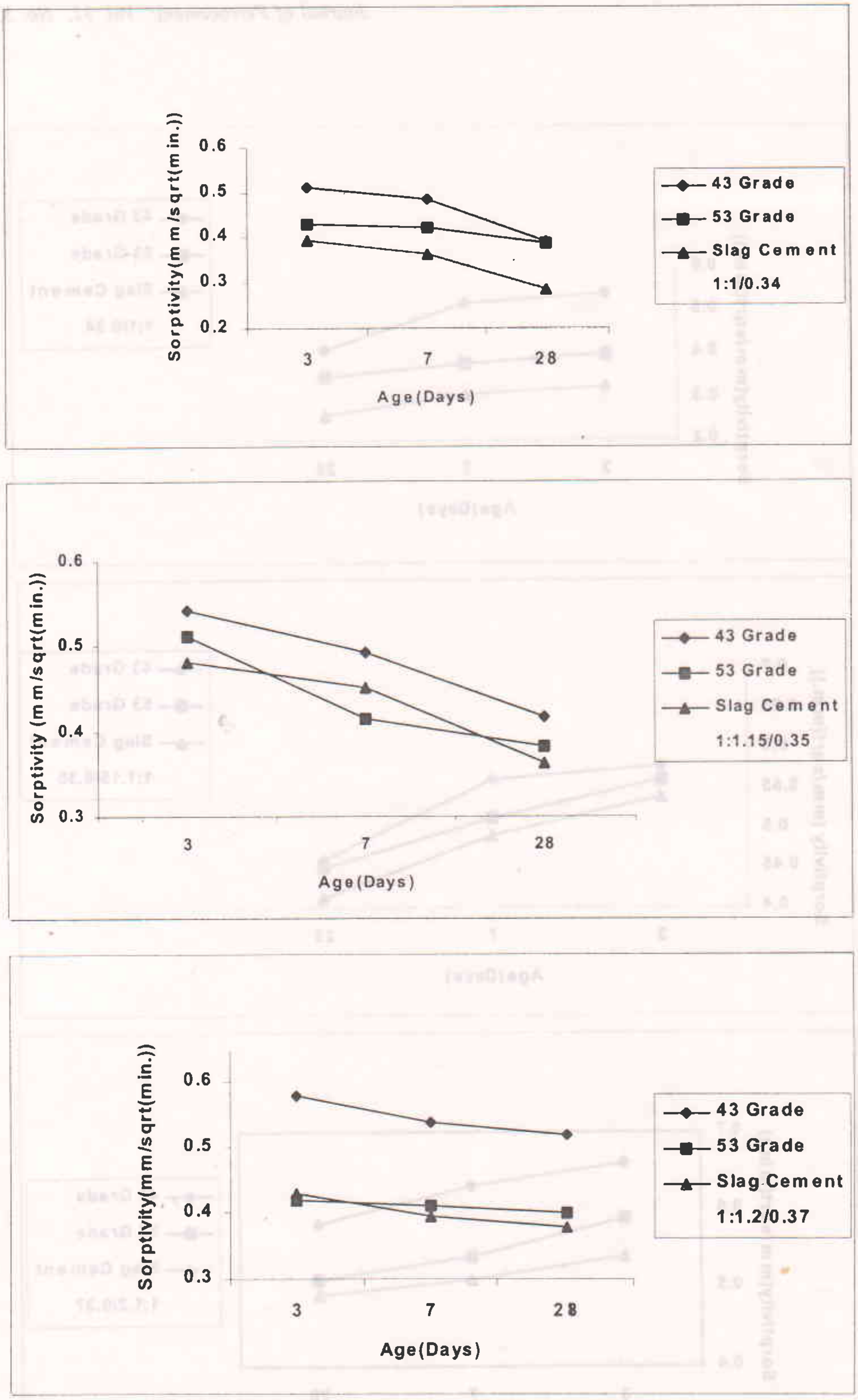


**Fig. 10. Sorptivity Vs Age (Stage 3- With Silica Fume and without Superplasticizer)**

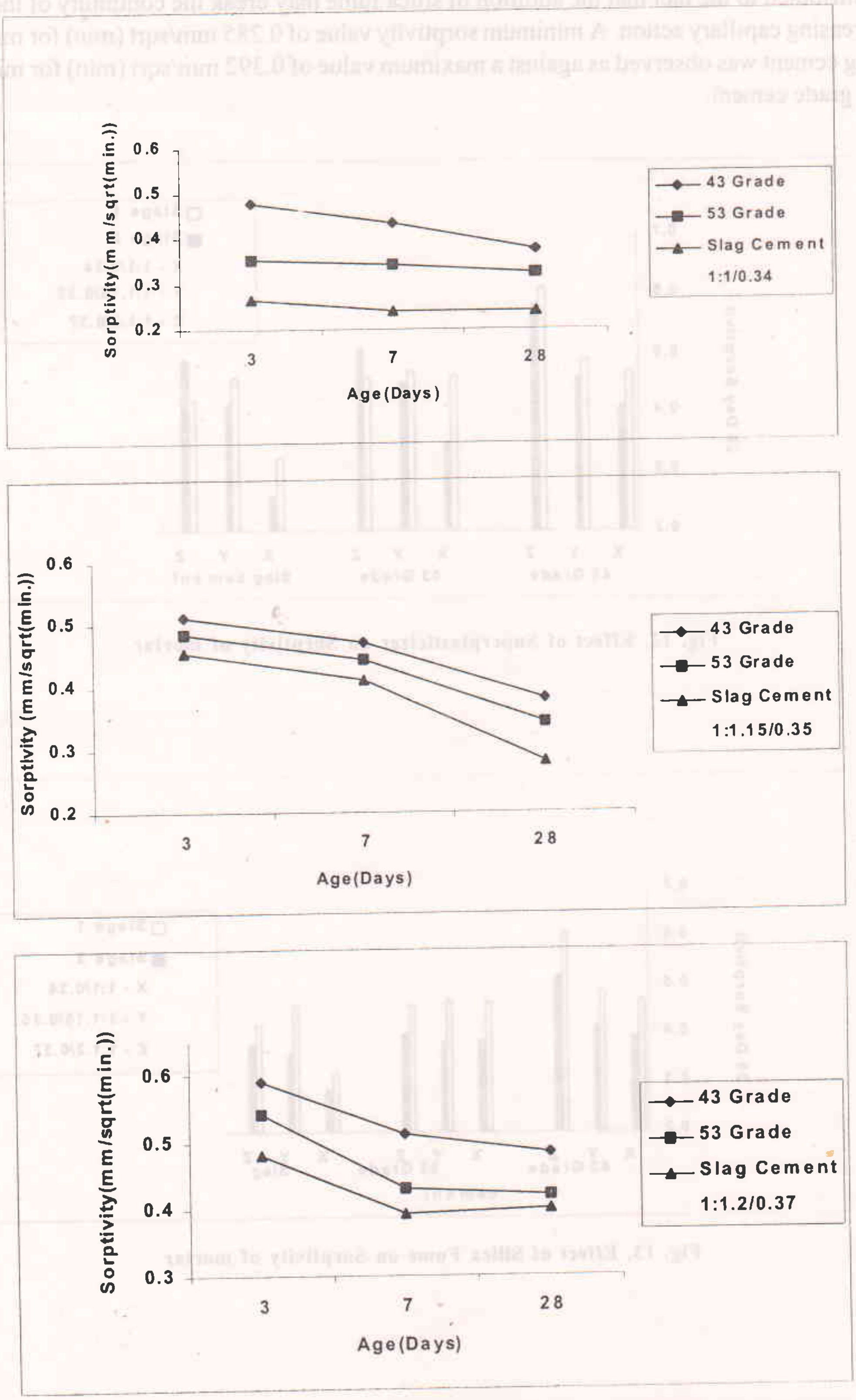


**Fig. 11. Sorptivity Vs Age (Stage 4- With Silica Fume and with Superplasticizer)**

## Effect of Silica Fume on Water Sorptivity

From Table 2 and Fig. 13, it can be observed that there is a decrease in sorptivity with partial replacement of cement by 10% silica fume for all the mixes and grades of cements used. The decrease may be attributed to the fact that the addition of silica fume may break the continuity of the pore size thus decreasing capillary action. A minimum sorptivity value of 0.285 mm/sqrt (min) for mix 1:1/0.34 using slag cement was observed as against a maximum value of 0.392 mm/sqrt (min) for mix 1:1/0.34 using 43 grade cement.

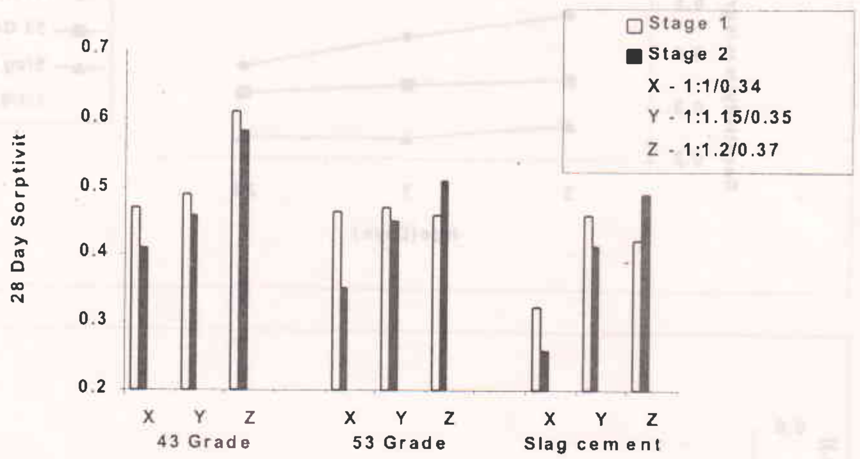


**Fig. 12. Effect of Superplasticizer on Sorptivity of mortar**

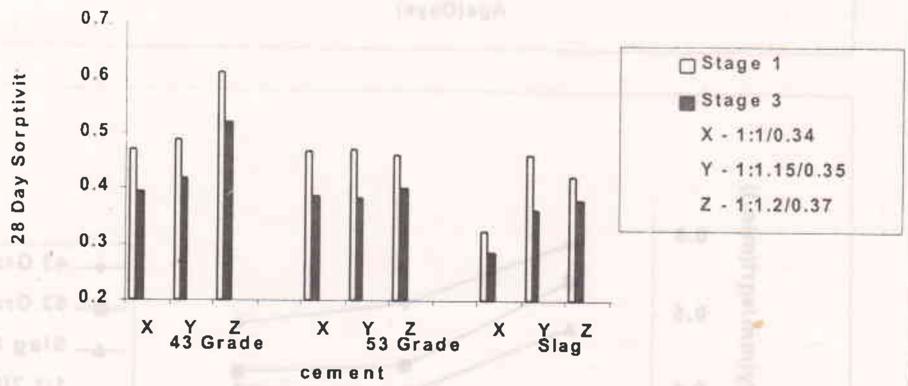


**Fig. 13. Effect of Silica Fume on Sorptivity of mortar**

**Combined effect of Silica Fume and superplasticizer on Water Sorptivity**

From Table 2 and Fig. 14, the test results obtained due to the combined effect of silica fume and superplasticizer on water sorptivity are reported. From the table and figure it is evident that there is a general decrease in sorptivity values irrespective of mix and grade of cement. The average decrease of sorptivity is 15% for slag cement, 23% for 53 grade and 20.3% for 43 grades. However, the minimum value of sorptivity 0.26 mm/sqrt (min) was reported for slag cement with mix 1:1/0.34 compared with that of Ordinary Portland cement.

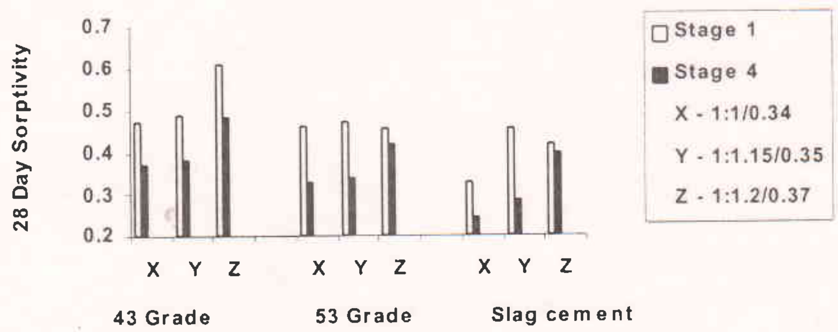


Fig. 14. Effect of Superplasticizer & Silica Fume on Sorptivity of mortar

## CONCLUSIONS

The following conclusions can be drawn from the results of shrinkage and sorptivity studies on rich mortar mixes consisting of silica fume and superplasticizer

1) High performance mortars with superior properties can be obtained by using the rich mortar mixes consisting of 10% silica fume and suitable superplasticizers.
2) For constant cement/silica fume ratio, the performance characteristics improved for lesser aggregate cement ratio for all the 3 grades of cement and more so for slag cement.
3) For the same quantity of replacement of cement by silica fume and for the same dosage of superplastizer, slag cement mortars have reported lesser shrinkage strains as compared to mortars developed using 43 and 53 grade ordinary Portland cements. The average percentage decrease in drying shrinkage was 45.8% in slag cement as compared to 32%, in 53 grade cement and 25.2% in 43 grade cement. The maximum percentage decrease in drying shrinkage for the High Performance Mortars developed was 56% using slag cement.
4) For the same quantity of replacement of cement by silica fume and for the same dosage of superplasticizer, slag cement mortar have reported lesser sorptivity as compared to mortars developed using 43 and 53 grade ordinary Portland cement.
5) The average percentage decrease in sorptivity is more in Ordinary Portland cement as compared to that of slag cement.

## REFERENCES


1. ACI Committee 549. 1982. *State of the Art report on Ferrocement (ACI 549-82)*. American Concrete Institute, Detroit: 26.
2. Agarwal S.K and Irshad Masood 1991, Effect of Superplasticizer in Rich mortar mixes containing locally available sands. *Journal of Ferrocement* 21(4): 351-357.
3. Kumar P.R, Seshu D.R and Rao C.B.K 2002, Studies on High Performance Mortar mixes (Part-1: Strength and Flow Characteristics of High Performance Mortars). *Journal of Ferrocement*
4. Kumar P.R et al. 2001. Superplasticizers in High Strength Mortars for use in Ferrocement woks. *26th International Conference on Our World in Concrete and Structures organized by CI-Premier Pte Ltd, Singapore during 27-28th August.*
5. IS: 12269-Code of Practice confirming to 53 Grade Ordinary Portland Cement
6. IS:8112-Code of Practice confirming to 43 Grade Ordinary Portland Cement
7. IS:455-Code of Practice confirming to Slag Cement.
8. IS: 650-Code of Practice confirming to Standard Sand for Testing of Cement.
9. IS:4031-Part 10- Standard Code of Practice for determining Shrinkage of Mortar.
10. Hall.C 1989, Water Sorptivity of mortars and concretes- A review. *Magazine of Concrete Research* 41(147): 51-61.