Comparison of Glass Powder and Fly Ash Effect on the Fresh Properties of Self-Compacting Mortars

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Abstract. This study is aimed to determine effects of glass powder on fresh properties of self-compacting mortars. Self-compacting mortars incorporating glass powder (SCMGPs) were designed with a water/binder ratio of 0.40 and a total binder content of 550 kg/m³. At first, the control mixture was produced with 20% fly ash and 80% cement of the total binder content without using the glass powder. Then, glass powder was used in the proportions 5%, 10%, 15% and 20% instead of fly ash in the mortars. Mini-slump flow and mini-v funnel tests experimentally investigated on SCMGPs to compare the effect of fly ash and glass powder. With increasing the amount of glass powder used in SCMGPs increased the amount of superplasticizer used to obtain the desired mini-slump flow diameter. So, the use of glass powder reduced the flow ability of SCMGPs in comparison to fly ash. Additionally, the compressive strength and flexural strength of the mortar mixtures were determined at the 28th day. The test results indicated that the mechanical characteristics of SCMGPs improved when the fly ash was replaced with glass powder in SCMGPs.

1. Introduction
Self-compacting concrete (SCC) which can be placed and compacted under its own weight without any vibration effort assures complete filling of formworks even when access is hindered by narrow gaps between reinforcement bars. So, high fluidity and cohesiveness of fresh concrete is extremely important for SCC [1, 2]. However, SCCs is designed with low water/binder (w/b) ratio and required high cement dosage. Therefore, large quantities of fine particles such as silica fume, blast furnace slag, fly ash and lime dust can be used instead of cement to prevent from dissolving of larger particles in the fresh mixture. Also, the stability and/or flow ability can be enhanced by using of chemical admixtures (superplasticizers) and it can increase the labour cost of materials [3-6]. But, the use of mineral admixtures not only reduces the material cost but also improves the workability and hardens the properties of concrete [7, 8]. However, due to the consumption of natural resources and CO2 emissions during cement production mineral admixtures such as glass powder (GP), silica fume, fly ash and blast furnace slag used instead of cement are extremely important for sustainable concrete and environment [9-11].

Glasses found in many areas such as window glass, bottle glass, decorative glass, beam tubes and ampoule glass in daily life, can be used in the production of concrete and mortar as glass aggregate or filler material and as a pozzolanic additive instead of cement after being an inert material [12-14]. Glasses are liquids that maintain their viscosity even at high temperatures. It is ceramic materials obtained from inorganic materials and composed of silicate system [15]. The main material of the glass is silica (SiO₂), which found as melted and dispersed in the amorphous structure provides a transparency feature. Waste glass cannot be used directly in concrete. After being removed from foreign materials, it is divided into classes according to grain size by grinding process. Coarse materials can be used instead
of aggregate in the concrete and fine materials such as glass powder are used instead of cement or filler material due to high silica content [16, 17].

When studies on glass powder are examined, in study performed by E. Orhan and M. Şahin [17] found that compressive strength of concrete ground waste glass powder additive showed an increase according to control concrete at 600°C and 900°C temperatures at the later ages. Dr. G. Vijayakumar et al. [18] found that the use of glass powder instead of cement increased the compressive and flexural strength of the concrete. Additionally, it can be concluded that glass powder can be used as cement replacement material up to particle size less than 0.075 mm to prevent alkali-silica reaction. N. A. Soliman and A. Tagnit-Hamou [19] indicated that the properties of the fresh ultra-high-performance glass concrete improved when the cement and quartz powder were replaced with non-absorbent glass-powder (GP) particles. However, it was determined that the strength improvement can be attributed to the pozzolanicity and mechanical performance of glass powder. Furthermore, when considering the literature studies, it can be seen that self-compacting mortar (SCM) may serve as a basis for the design of concrete and properties of SCMs highlight the workability of SCCs [20, 21].

The main aim of this study is to compare the effects of fly ash and glass dust on the fresh and mechanical properties of self-compacting mortars. For this purpose, firstly, the control mixture was produced by using 80% cement and 20% fly ash without glass powder. Then, glass powder was used in the rates of 5% 10% 15% and 20% instead of fly ash by keeping the cement dosage constant. Tests carried out on fresh SCMs involved mini-slump flow and mini-v funnel flow time. Additionally, the compressive and flexural strength of SCMGPs were tested the 28 days.

2. Materials and Methods

2.1. Materials

CEM I 42.5 R type Ordinary Portland cement was used as well as class F fly ash and glass powder as mineral additive materials in the production of mortar samples. Physical and chemical properties of cement, fly ash and glass powder are given in Table 1. Additionally, SEM images analysis of fly ash and glass powder are given in figure 1. Natural fine aggregates utilized in this study were crushed and natural river sand with specific gravities of 2.63 and 2.67 and grain sizes 0-2 mm and 0-4 mm, respectively. High Range Water Reducing Admixture (HRWRA) with a specific gravity of 1.07 was employed to achieve the desired workability of SCMs.

| Chemical Analysis (%) | Cement | Fly Ash | Glass Powder |
|-----------------------|--------|--------|-------------|
| CaO                   | 62.58  | 2.24   | 9.89        |
| SiO₂                  | 20.25  | 57.2   | 71.79       |
| Al₂O₃                 | 5.31   | 24.4   | 1.04        |
| Fe₂O₃                 | 4.04   | 7.1    | 0.11        |
| MgO                   | 2.82   | 2.4    | 4.10        |
| SO₃                   | 2.73   | 0.29   | 0.23        |
| K₂O                   | 0.92   | 3.37   | 0.20        |
| Na₂O                  | 0.22   | 0.38   | 12.41       |
| Loss of Ignition      | 2.96   | 1.52   | -           |
| Specific Gravity      | 3.15   | 2.04   | 2.60        |
| Blaine Fineness (m²/kg)| 326    | 379    | -           |
2.2. Preparation of the mortar mixtures

A total of 5 self-compacting mortar (SCM) mixtures were produced with a constant w/b ratio of 0.40 and a total cementitious material content of 550 kg/m$^3$. SCMs were produced incorporating the binary cementitious blends of 20% (fly ash+glass powder) and 80% Portland cement. In the control mixture, 20% of total binder content was fly ash (110 kg/m$^3$). Then, glass powder was replaced with fly ash in the rates of 5% 10% 15% and 20%, respectively. The mixes were all the same except the fly ash being replaced by glass powder at different proportions as illustrated in table 2. In the production stage of SCMGPs, the mixing process was kept constant to provide the same uniformity and homogeneity in all the mixtures according to ASTM C109/C 109M-99 [22]. SCMs were designed to give a mini-slump flow diameter of 24–26 mm which was achieved by using the different amounts of HRWRA [20]. For this, trial batches were produced for each mixture until the desired mini-slump flow was obtained.

| Code Number | Water/Cement | Fly Ash | Glass Powder | Natural Sand | Crushed Sand | HRWRA |
|-------------|--------------|---------|--------------|--------------|--------------|-------|
| SCMGP0      | 0,4          | 440     | 110          | 0            | 1077,28      | 454,78 | 4,3  |
| SCMGP5      | 0,4          | 440     | 82,5         | 27,5         | 1082,72      | 457,07 | 4,4  |
| SCMGP10     | 0,4          | 440     | 55           | 55           | 1088,14      | 459,36 | 5,2  |
| SCMGP15     | 0,4          | 440     | 27,5         | 82,5         | 1093,56      | 461,65 | 6    |
| SCMGP20     | 0,4          | 440     | 0            | 110          | 1098,99      | 463,94 | 6,8  |

2.3. Test procedures

Mini-slump flow and mini-v funnel tests were performed according to EFNARC committee (European Federation for Specialist Construction Chemicals and Concrete Systems) [20] to determine the workability characteristics of SCM. In the mini-slump flow experiment, the SCM blends were filled in the cone without subjecting to any compaction, and the average spreading diameter of the fresh mortar was measured in two directions perpendicular to each other and then averaged.

In order to determine the viscosity properties of the samples, the mini-v funnel test apparatus was used. After filling the mini-v funnel with fresh mortar, the release time of mortar was measured by opening the bottom cover.

After 28 days, compressive strength and flexural strength according to ASTM C109/C 109M-99 [22] and ASTM C348-14 [23] of the samples were determined, respectively. Three prismatic specimens in dimensions of 40x40x160 mm were used to determine flexural strengths of the samples. Then, flexural
strength of mixtures was determined by taking the average of the results obtained from 3 samples. Compressive strength of the samples was determined by using the 6 pieces obtained after the flexural test. It was performed pressure loading to the samples by placing a square piece in size of 4 mm on these pieces and compressive strength of mixtures was determined by taking the average of the results obtained from 6 samples.

3. Results and Discussion

3.1. Mini-slump flow diameter
The values of mini-slump flow for control mortar and SCMGPs are presented in figure 2. When considering mini-slump flow diameters measured in fresh state, the best result was obtained from SCMGP0. The amount of HRWRA used in mortar were increased with the increasing amount of glass powder, however, the spread diameter of SCMGPs was decreased. The basic reason for this is that fly ash has more spherical structure than glass powder as seen in SEM images (figure 1). Therefore, a more angular structure of the glass powder compared to fly ash affected the fluidity negatively, and the fluidity of SCMGPs decreased as the volume of glass powder in mixes was increased.

![Figure 2. Mini-slump flow diameter changes for SCMGPs](image)

3.2. Mini-v funnel flow time
The changes in mini-v funnel flow time of fresh mortars are graphically given in figure 3. As seen from figure 3, mini-v funnel flow time increased steadily with increased of the amount of fly ash used in mortar. As it is known, the effect of a material on fluidity is directly related to its spherical shape. As seen figure 1, the structure of the glass powder is more angular than that of fly ash. For this reason, mini-v funnel flow time decreased with increasing amount of glass powder used in mortar as observed in SCMGP20. It can be concluded from the test results, for SCMGPs, fluidity of fly ash is more than that of glass powder.
3.3. Compressive strength

Variations of compressive strength of SCMGPs are graphically shown in figure 4. As it is seen in figure 4, the increment of glass powder amount increased the compressive strength of SCMGPs. While the compressive strength of the control mortar (SCMGP0) was measured as 61.37 MPa, the compressive strength of SCMGP20 was obtained as 72.33 MPa. Similarly, the compressive strength of mortar containing 20% glass powder increased in the ratio of 17.76% compared to the control mortar. As it is known, pozzolanic additive materials in concrete form C-S-H gels and enhance strength by connecting Ca(OH)₂ formed hydration result of cement and water with a highly active SiO₂ in the structure. As a result, glass powder used instead of fly ash can increase the strength of SCMGPs. This result was supported by the study of N.A. Soliman and A. Tagnit-Hamou [24] indicated that the effect on compressive strength of glass powder is more than that of silica fume. However, when the physical and chemical properties of materials given in Table 1 are considered, the amount of silica (71.79%) in glass powder is greater than the amount of silica (57.20%) in fly ash. Therefore, it has been found that glass powder provides more strength for SCMGPs with respect to fly ash.
3.4. Flexural strength
The graphical representation of flexural strength values of SCMGPs is given in figure 5. The increment in the amount of glass powder used instead of fly ash increased the flexural strength as observed in compressive strength results of SCMGPs. Flexural strength of SCMGP20 increased by 57.47% compared to SCMGP0. Similar to compressive strength test results, glass powder incorporating much more active silica than that of fly ash enhanced the flexural strength of SCMs with glass powder.

![Flexural Strength Graph]

**Figure 5.** Flexural strength of SCMGPs the 28 days

4. Conclusions
Based on the investigation, the following conclusions can be drawn;

- The use of glass powder instead of fly ash affected in negative direction the fresh properties of self-compacting mortars. Mini-slump flow diameter decreased gradually with the increasing ratio of glass powder. However, mini-v funnel flow time increased gradually with the increasing amount of glass powder used in SCMGPs. It can be concluded that the workability of SCMGPs was particularly deteriorated with the usage of glass powder due to fly ash has a more spiral structure than that of glass powder.

- The usage of glass powder instead of fly ash in the production of SCMGPs increased the mechanical properties such as the compressive and flexural strength. As it is known, one of the most important properties expected from mineral admixtures incorporated with the mortar or the concrete as a second binder material increase the strength and durability by forming C-S-H jels thanks to active silica. Silica content of glass powder is more than that of fly ash. Therefore, in this study, glass powder was gained more compressive and flexural strength to SCMGPs.

- In this study, the effects of fly ash and glass powder on fresh and hardened properties of self-compacting mortars were compared. As a further study, glass powder will be used at different rates instead of cement. So, it will be investigatged the effect of glass powder on fresh and hardened properties of self-compacting mortars.

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