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# The effects of using Micro-$SiO_2$ with Ground Granulated Blast-Furnace Slag of Esfahan Steel Company in Concrete

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## ABSTRACT

**In this study, the properties of concrete with different amounts of Ground Granulated Blast-Furnace Slag (GGBFS) has been studied. In another part, the test deals to assess the properties of concrete containing GGBFS with micro-$SiO_2$. The results show that the slag has pozzolan properties and its use up to 20% in the concrete, has no harmful effect on concrete properties. The simultaneous use of micro-$SiO_2$ with blast furnace slag have little effect, as well as micro-$SiO_2$ covers the defects caused by the use of slag. The results indicate that the use of micro-$SiO_2$ and slag has good effects on the strength of concrete up to a certain age, so that its compressive strength is increased. Water-cement ratio was 0.42 and 12.5 mm for maximum size of aggregate and cement content in concrete was 425 kg per cubic meter. Compressive strength of concrete samples was measured at ages 7, 28, 56 and 90-day and flexural and tensile strength and water absorption after 28-day and 90 days also was measured.**


***Key words:*** *concrete, compressive strength, GGBFS, Micro-$SiO_2$*

## Introduction

The rapid development and increasing access to technology and growing initiatives in the field of construction materials made production of "capable concrete" possible. Production of such concrete is possible using micro-SiO2 with a super plasticizer additive, the use of water - cement ratio and use of low natural pozzolan. Since the development of industry and the subsequent expansion of industrial production, mankind has always been faced with such an unintentional and unwanted materials produced beside the main product. Some called these products as extra and knew them as unused, and some knew these materials as byproducts and believe that this material can be used in other applications (Caijun and Jueshi, 2000). In this regard, the iron and steel industry is no exception and has been met a subsidiary in the production of iron and steel products. Ground blast furnace slag is from the steel industry. With increasing development of the world's steel production an issue in a ground blast furnace slag is also growing (Gielen and Moriguchi, 2001). Slag which is non-metallic material is obtained as a byproduct during the production of the metal material, the experience of other slag in the cement industry prompted us to study the properties and characteristics of the effect of adding it on properties of ordinary Portland Cement (OPC). The results of the other two types of iron and steel slag to be compared. In general, steel slag that is produced in a blast furnace in use in other industries, steel slag is older than the other. The slag, due to its chemical properties in different applications, among which can be used in the cement industry, the construction of railways, roads, industrial cartridge used in the building as well as the industry's stone wool production (Kourounis et al, 2007).

One of the most important use of slag cement is its usage in concrete production as a supplement to replace part of the Portland cement used in concrete as well as concrete advantages include reduced water requirements, increase the setting time, lower heat of hydration, reducing the capillary porosity, improve the microstructure of concrete, increased strength to chemical attacks and destructive influence occurs in concrete (ACI Committee 233, 2005- Mindess et al, 2002). It should be noted that unlike other pozzolan which has adhesive properties by reacting with calcium hydroxide in the cement paste, no adhesive material produced slag alone is capable of adhesion. Thus, unlike conventional pozzolan to 30% by weight of cementitious materials used, the furnace can be consumed by more than 70% by weight of cementitious materials. The first research on the powder mill slag as a cementitious material was done in 1774 by a man named Laureate who used slag powder in the manufacture of a limestone concrete (Oliver,

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1987). Then the use of slag cement in France in 1989, which was made of milled powder and slag cement, the mixture used were carried out for the construction of the Paris Metro. Slag powder mixed in cement production is now close to 20% by weight of cement used in Europe (Oliver, 1987). During the trials that the use of slag powder in concrete preparation lead to the conclusion that the addition of slag reduces the heat of hydration. The use of slag powder in percentages higher than 60%, leading to a sharp decline in strength and concrete performance (Sivasundaram, 1992) but using slag powder as a substitute for cement in the amount of 30 to 60% obtained acceptable results of the compressive strength. (Malhotra, 1994) With regard to the strength of concrete containing slag is low in the short term, the use of micro-$SiO_2$ in concrete slag can improve the properties. The research was conducted in the context of adding 5 to 10% micro-$SiO_2$ alone, where 30 to 50 percent and 50 to 70 percent slag cement is used to increase the strength of concrete and concrete containing 7 days Portland slag cement containing 60%, 33% and 7% of the maximum strength of the concrete, slag micro-$SiO_2$ and high strength concrete made 7 and 28 days, the other such as concrete evidence has been shown (Ozyildrim, 1994).

Also, research has been evaluated against the overhead concrete sulfate (Hooton and Emery, 1991). He achieved the results that can be added to concrete strength against sulfate slag concrete mix design with added percentage point. In studies that have been conducted on this subject it can be considered and compared to the compressive strength of concrete, changing parameters to cement ratio, the percentage of micro-$SiO_2$ , slag, and combinations thereof as cement replacement and eventually determine the best mode of composition This material cement in concrete (optimized percent) in terms of achieving the maximum compressive strength is (Mostofinejad et al., 1381) in other research that has been done as sand slag concrete is used in the preparation style (Mayfield and louati, 1990). With regard to the processing applied in the investigation of slag grain by grain size suitable for the lightweight concrete with a specific weight of less than 1850 per cubic meter used compressive strength 50 MPa is obtained. In recent years more research into the slag concrete is multicomponent, in this study the impact of supplementary cementitious materials very fine ash, fly ash and ground blast furnace slag for normal F-type two-component and three partially on the strength and durability of concrete with compressive strength and electrical qualification tests at ages 7, 28, 56 and 90 were studied. The results show for the concrete containing different amounts of fly ash is very fine ground blast furnace slag improves long-term durability is 7.5%. With the increasing use of very fine ash to 15 percent improvement in durability is made. With the increasing use of very fine ash to 15 percent improvement in the durability. In addition, the use of fly ash is very fine, except that the amount of slag in the concrete is low (about 15%), a drop strength of all ages (Bagheri et al., 1389 and 1390) also study the effects of fly ash and slag mixed a mixture of two and three minor part on the properties of fresh concrete and concrete compressive strength was evaluated results show that the compressive strength of concrete two-component mixture of three minor ashes will rise. (Tikalsky et al, 2007) on the use of slag powder despite significant amounts of ground blast furnace slag (blast furnace and converter) in a steel mill in Isfahan, only a small part of it as a supplementary cementitious material used in cement production. Much of the slag is disposed of in cold and then the depot. The results reported relatively limited research suggests that iron-ground blast furnace slag-forming reaction interior is relatively low. As a result, the gross domestic product slag in concrete ways to improve the performance of important research needs of the country. In addition, a by-product of micro-$SiO_2$ produced by electric arc furnaces in the production process is Ferrosilice alloys. Fume gray to white powder that can be classified as additives with cement properties. Micro-$SiO_2$ in the form of gel is applied as a gel which contains 51 water, 45% and 4% micro-$SiO_2$ powder additives and water reducer (Li, 2004). Leaching of calcium hydroxide released by the hydration of cement and the lack of fine pores of the filler, reducing the strength of concrete and concrete can intensify the vulnerability. Non-adherence to the reinforcement of concrete is in addition to and in fact such a structure in terms of penetration and acquisition of adequate strength, durability and low safety margin is not very good. The use of micro-$SiO_2$ in the concrete, calcium hydroxide solution (unstable) enclosed between aggregate and fittings to become insoluble calcium silicate and micro-$SiO_2$ particles are planning to change the structure of concrete components and between grains of rock and filled the cement particles, thus Similarly low concrete permeability and thus the consistency and durability of the concession period is increased. In another study is done of the concrete in various grades of cement and micro-$SiO_2$ have been investigated. The use of 6, 8 and 10% micro-$SiO_2$ concrete with cement content of 300, 350 and 400 have been investigated. The results of this study indicate that the micro-$SiO_2$ have a noticeable impact on the strength of concrete. The effect is related to the use of 10% micro-$SiO_2$. The highest increase in strength occurs between 7 and 28 days (Family and Bagheri, 1388).

## MATERIALS AND METHODS

### Aggregate

Sandy materials of MANZARIYEH mine mineral sands was used with the best characteristics of the tribute. Both materials were mountain broken. Building a good size and standard values. The grain size of coarse aggregate (gravel) of 5.12 mm and a fineness modulus of aggregate (gravel) was 2.9**.**

### Slag and micro-$SiO_2$ *:*

Slag used in this research is GGBFS. The waste slag jaw to become smaller, and then ground in a mill small jaw size to the point that can be used to have the concrete. The old version of crushed seeds of 200 mesh (75 microns) has passed. Chemical characteristics are shown in Table 1. Consumer converter slag. Fume used in this experiment, sashimi trade name, product of building chemistry and chemical compounds listed in Table 1.

**Table 1. The chemical composition of silica fume and slag**

| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | Mgo | $SO_3$ | $K_2O$ | $Na_2O$ | CaO | $MnO_2$ | $TiO_2$ | $P_2O_5$ | L.O.I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **micro -$SiO_2$** | 3.93 | 1.1 | 85 | 1.1 | 7 | 7 | 3 | 2.1 | - | - | - | 5.2 |
| **slag** | 37.45 | 8.85 | 0.14 | 9.84 | 0.001 | - | 0.99 | 39.45 | 0.628 | 1.622 | 0.119 | 0.02 |

### *Cement*

Portland cement Type I is used, and Fineness of cement is 425(kg/m3). Its physical properties shown in Table 2.

**Table 2. The physical of cement**

| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | L.O.I | Total alkali | $C_3A$ |
|---|---|---|---|---|---|---|---|---|---|
| Shahrekord cement | 5.21 | 0.5 | 1.3 | 7.63 | <7.1 | ≤2 | ≤3.1 | ≤3 | ≤5.7 |
| ASTM | ≥20 | ≤6 | ≤6 | - | ≤6 | ≤3 | ≤3 | - | ≤8 |

### *Water*

Water used in this study is sharekord water used in this experiment. Profile of water is given in Table 3.

**Table 3. Profile of water**

| PH | **Ammonium** (mg/lit) | **Sulfates** (mg/lit) | **Total hardness** (mg/lit) |
|---|---|---|---|
| 6.7 | 40 | 29 | 205 |

### *Super-Plasticizer*

In this experimental study, because of using micro-sio2 and high water absorption, Plasticizer should have been used. The Plasticizer is POWER PLAST.SM. Features of the Plasticizer was in accordance with the standard ASTM C 494-81 TYPE F. The properties of the super plasticizer used in the study were a PH of 5, a dark-brown color, a specific gravity (g/cm³) of 1.20.

### *Mix design and development of samples*

To test the 2 phase of work is intended. In the first phase, GGBFS for 10, 20, 30 and 40% cement replacement used (Table 4). In the second phase to examine the effect of micro-SiO2 and GGBFS, micro-SiO2 of 5, 10 and 15% as replacement of cement with slag at 10, 20, 30 and 40 percent, and the effect of time on concrete study (Table 5). The mechanical properties such as compressive strength at ages 7, 28, 56 and 90 days, flexural and tensile strength at 28 days and the water absorption was measured at 28 days. Thus, 17 mix design based on ACI regulations for the production of samples and 10 samples for each mix design cube with dimensions of 10 cm to determine the compressive strength of 7, 28, 56 and 90 days and water uptake test, three samples of the moment MOR and a cylindrical sample for testing for tensile test was made. Mixer with a capacity of 120 liters to produce the samples used. The aggregate mixed with a small amount of water in a mixer and then mix the cement and slag added. Then the remaining water with a super plasticizer added to the mixture and the mixture is mixed for 4 minutes. The concrete is poured into molds and compression and vibration in accordance with the standards was conducted on the samples. It should be noted that due to the high surface area micro-sio2 mixed with some water to separate plan for sludge mixture, and finally added to the project. Thus, to test samples made and after testing slump, are molded. After a day until the test samples extracted from the mold and were treated in a solution of lime water saturation. After the experiment, the samples retrieved by the standard jack 2000-KN accordance with the standard BS 1881: Part 116 have been tested. The long-term water absorption in accordance with ASTM C642 standard is performed. In naming, M represents micro-Sio2 and Sk represents Ground Granulated Blast-Furnace Slag (GGBFS) and the number written in front of each indicated percent cement replacements

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**Table 4. Mixing projects in the first phase**

| Mix design name | Gravel (kg/m3) | Sand (kg/m3) | Water (kg/m3) | Slag (%) | Slag (kg/m3) | cement (kg/m3) | plasticize (kg/m3)r |
|---|---|---|---|---|---|---|---|
| Sk10 | 748 | 932 | 167 | 10 | 41 | 369 | 246 |
| Sk20 | 748 | 932 | 167 | 20 | 82 | 328 | 246 |
| Sk30 | 748 | 932 | 167 | 30 | 123 | 287 | 246 |
| Sk40 | 748 | 932 | 167 | 40 | 164 | 246 | 246 |

**Table 5. Mixing projects in the second phase**

| Mix design name | Gravel ($kg/m^3$) | Sand ($kg/m^3$) | Water ($kg/m^3$) | Micro-(%) $Sio_2$ | Micro-$Sio_2$ ($kg/m^3$) | Slag (%) | slag ($kg/m^3$) | cement ($kg/m^3$) | plasticizer ($kg/m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| M5Sk10 | 748 | 932 | 167 | 5 | 20.5 | 10 | 41 | 348.5 | 254.2 |
| M5Sk20 | 748 | 932 | 167 | 5 | 20.5 | 20 | 82 | 307.5 | 254.2 |
| M5Sk30 | 748 | 932 | 167 | 5 | 20.5 | 30 | 123 | 266.5 | 254.2 |
| M5Sk40 | 748 | 932 | 167 | 5 | 20.5 | 40 | 164 | 225.5 | 254.2 |
| M10Sk10 | 748 | 932 | 167 | 10 | 41 | 10 | 41 | 328 | 262.4 |
| M10Sk20 | 748 | 932 | 167 | 10 | 41 | 20 | 82 | 287 | 262.4 |
| M10Sk30 | 748 | 932 | 167 | 10 | 41 | 30 | 123 | 246 | 262.4 |
| M10Sk40 | 748 | 932 | 167 | 10 | 41 | 40 | 164 | 205 | 262.4 |
| M15Sk10 | 748 | 932 | 167 | 15 | 61.5 | 10 | 41 | 307.5 | 328 |
| M15Sk20 | 748 | 932 | 167 | 15 | 61.5 | 20 | 82 | 267.5 | 328 |
| M15Sk30 | 748 | 932 | 167 | 15 | 61.5 | 30 | 123 | 225.5 | 328 |
| M15Sk40 | 748 | 932 | 167 | 15 | 61.5 | 40 | 164 | 184.5 | 328 |

## The results of experiments

### Compressive Strength

Samples compressive strength histogram is shown in Figure 1 of the first phase and the second phase for samples shown in Figure 2 to 5. Observed that the volume resistivity decreases with increasing pozzolan. This reduction decreased with increasing age of the samples is confirmed the blast furnace slag pozzolanic properties. Also, one can determine that whatever age is higher, the growth of strength in samples containing higher percentages of pozzolan, which represents the most appropriate function in the elderly is pozzolan. The figure is the difference between the samples at the age of 7 days due to the growth of activity has been very high pozzolan concrete age, the age difference is less than 90 days ago. At the age of 7 days pozzolan only as filler fine and there is no pozzolanic activity. At an early age have a large gap compared to control samples this difference by increasing the processing time is less. During the 7 days of sharp decline in strength to the control samples. This reduction has been high for the percentage of pozzolan. Slag from 10% to 20% decreased by increasing the compressive strength and then increased with increasing slag Sk30 They are found in the compressive strength. The maximum strength is about 10 percent slag and slag of least strength is 50%, adding more slag strength still occurs reduction. Compressive strength increased and then decreased with increasing of slag. a sudden decrease in the sample strength is seen by Sk20 at an early age and is more pronounced. Pozzolan increases 40 percent, another jump in reducing strength was observed.

The second phase samples of Figures 2 to 5 it is observed that in all shapes, micro-sio2 at all levels and in all projects has been dramatically increases the compressive strength of concrete, so that all projects using micro-sio2 had higher strength than concrete containing slag have gained. Strength increases as the micro-sio2 content increases. In this graph it is notable that all samples are significantly different in strength, but there is little difference in the age of 7 days. The samples containing 10% slag strength in 56 days more than the others because it is the removal of the lower cement-samples, slag and micro-sio2 increased slightly with the increase in compressive strength can be seen that, due to increasing the amount of cement is more and sample M5Sk10, M10Sk10 and M15Sk10 and M20Sk10 increase in 56 days, even compared to the control. But in other cases the growth has been steady strength. With the addition of micro-sio2 not only strength reduced but also due to the addition of pozzolan to fully offset the increase much strength seen in cases. Note in Figure (5-12), the fact that the compressive strength M5Sk20 plan M5Sk10 and 7 days, respectively, 3 and 2 percent of their control strength (Sk10 and Sk20), but less in other projects at the age of 7-day than control their strength to age and the percentage of slag concrete is more appropriate. It also underscores that role just fine micro-sio2 filler until the age of 7 days and the majority of its activity in the age of 7 to 28 days. Figure (5-14) can grow again caused by the use of the micro to control and observe without fume. At the age of 7 days, samples containing less than 15% micro-sio27-day strength gained control concrete, but with age has increased concrete strengthen than control concrete, notably, unlike in the project sample slag containing 10% Other projects shows a slight increase in those aged 56 and 90 days and it can be seen in other age groups in all cases, samples containing micro-sio2 increased the volume resistivity of the sample and nothing significant in the control sample. Ideally, use 10 percent to 15 percent pozzolan in micro-sio2. The forms can then conclude that in all proportions and at all levels of micro-sio2 pozzolan, increased strength is to be acceptable. At other times the amount of the increase and decrease processing is different. For example, in samples of 7 days with increasing as well as the percentage of micro-sio2 pozzolan, strength is further reduced. Growth percent, for samples of 28 days compared to samples containing no micro-sio2, pozzolan property is very high and because of this act, and to act at this age micro-sio2 pozzolan incomplete in 28 days.

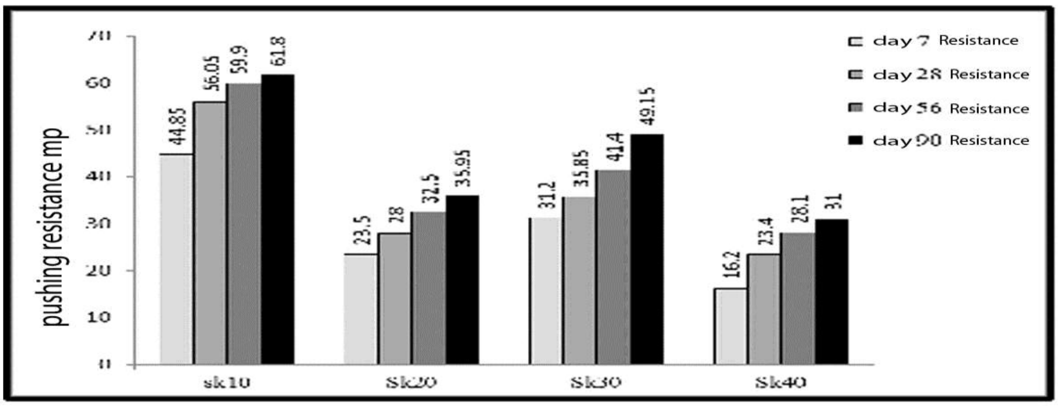


**Figure 1 - compressive strength in the first phase**

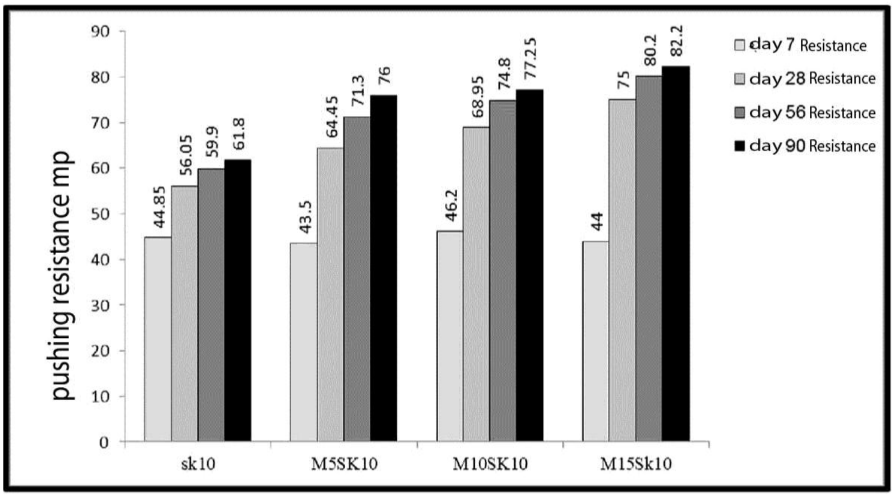


**Figure 2 - compressive strength in the second phase**

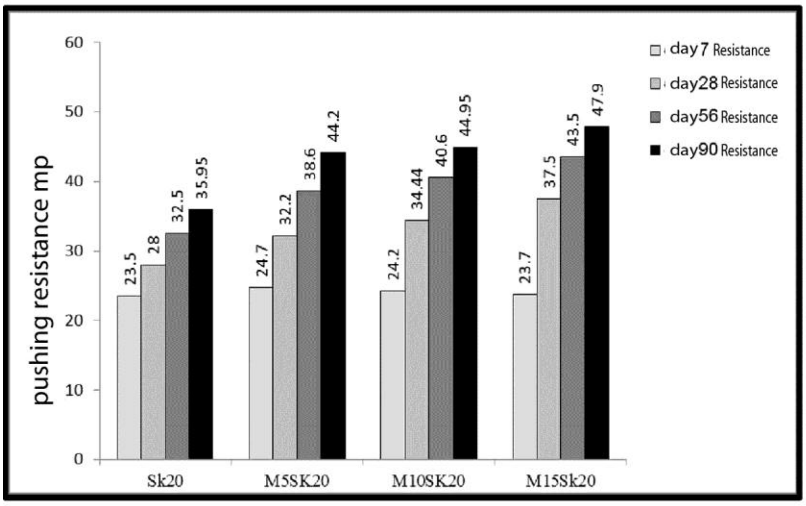


**Figure 3 - compressive strength in the second phase**

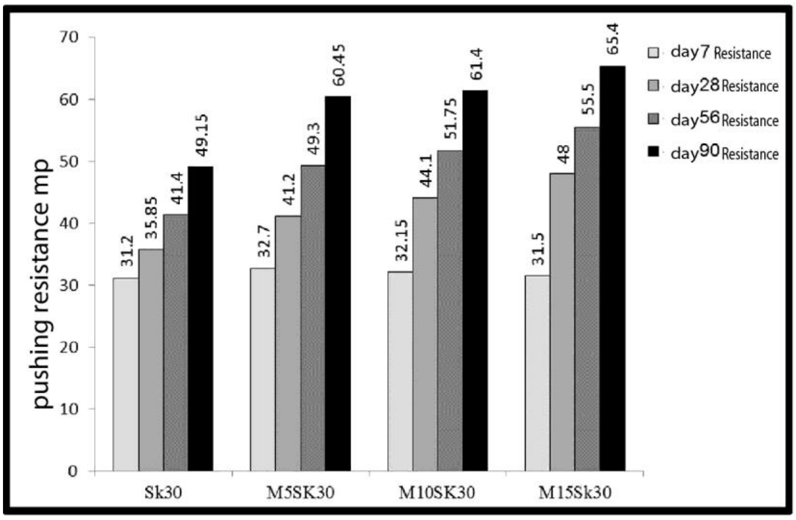


**Figure 4 - compressive strength in the second phase**

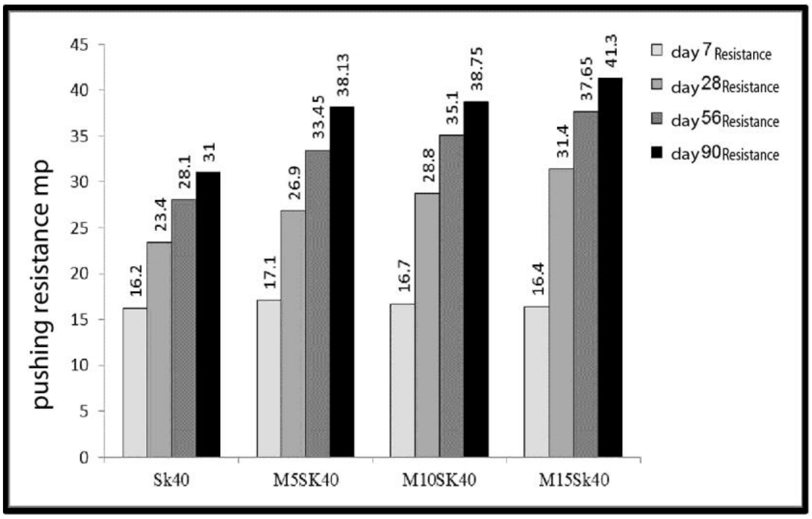


**Figure 5 - compressive strength in the second phase**

***Flexural strength***

In Figure 6, the results of samples containing blast furnace slag is intended as a control and the addition of micro-sio$_2$ based slag can be seen in flexural strength. Design and samples with blast furnace slag cement from 10 to 20% increase 27% decrease strength and then decreases with the increase of slag strength remains constant, we can say that regular trend in this study did not, and 30 percent after having decreased strength, as the graph is known to add micro-sio$_2$ in samples containing slag reduces the bending strength, except samples M5Sk20 with increased flexural strength The rate is 2. In the 5% micro-sio$_2$ and slag increases strength first increases and then decreases are increased but the percentage compared to the control sample corresponds to a decrease in strength slag and micro-sio$_2$ will be with the addition of slag in by adding 10% the flexural strength of reduced is and to increase the strength of the slag reduction. However, the sample contained 15 and 20% of SF samples containing 10% slag were 2 and 4% increase is observed in the flexural strength. In this phase, the flexural strength of least strength M15Sk10, M15Sk40 is related to the overall samples containing 40% slag in every plan and is the lowest flexural strength among projects.

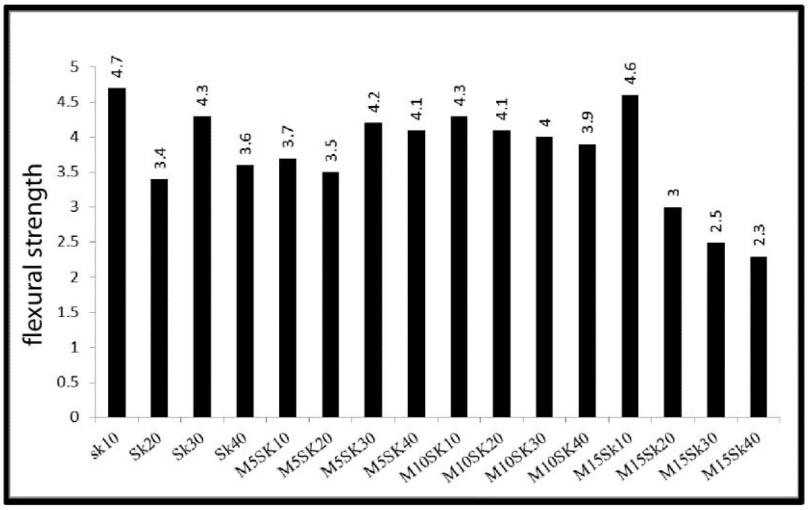


Figure 6 - flexural strength first and second phases

***Tensile strength***

Figure 7 can be obtained from the combination of micro-sio$_2$ and blast furnace slag shows better results than the samples containing slag-off. In the case of adding micro-sio$_2$ to control samples than in samples of slag only when there place-show. In a certain percentage of micro-sio$_2$, for example, a 5% increase blast furnace slag micro-sio$_2$ no specific trend observed in tensile strength. The tensile strength of 10% and 10% micro-sio$_2$ pozzolan cement and minimum tensile strength of the use of micro-sio$_2$ pozzolan cement by 40% and 20% obtained respectively.

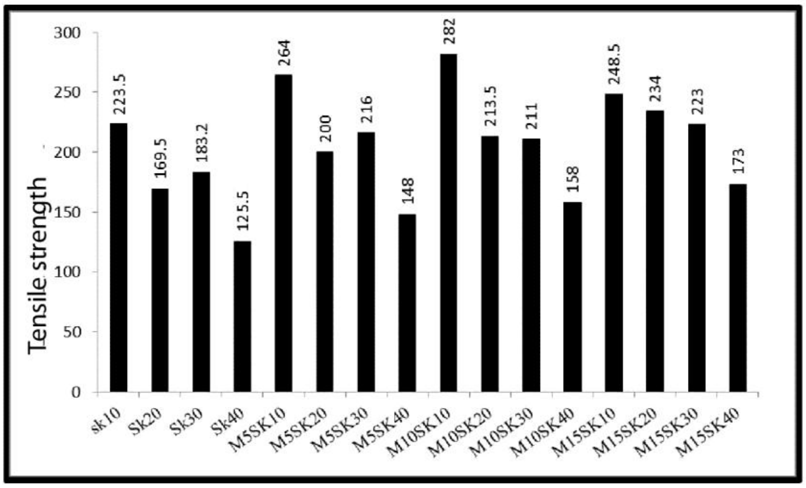


**Figure 7 - Tensile strength of the first and second phase samples**

***Water absorption***

The use of slag samples containing micro-sio$_2$ constant with water intake, and the slag increases water absorption is reduced more, except for samples containing 15% micro-sio$_2$ increased with increasing slag and micro-sio$_2$with samples containing 20% increased furnace was first reduced and then increased, it should be noted that in the case of all samples in a range of 20% micro-sio$_2$. It is clear from the results of samples containing micro-sio$_2$ by increasing its water absorption than the control sample corresponds to the percentage of slag increased by 10% for samples containing 10% slag and micro-sio$_2$.

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Samples M5Sk10, M5Sk20, M5Sk30 and M5Sk40 to their control samples of slag corresponding to the 21.15, 20, 15.83 and 3.77 percent increase in water absorption, respectively. Samples M10Sk10, M10Sk20, M10Sk30 and M10Sk40 to their control samples of slag corresponding had a 12.69, 16, 17.07 and 6.14 percent change in water absorption. Samples M15Sk10, M15Sk20, M15Sk30 and M15Sk40 compared to the control sample corresponds to the percentage of slag 17.30, 4.61, 13 and 0.75% had changes in water absorption respectively. M5Sk10 has maximum water absorption of the sample and the sample M15Sk10 has the lowest

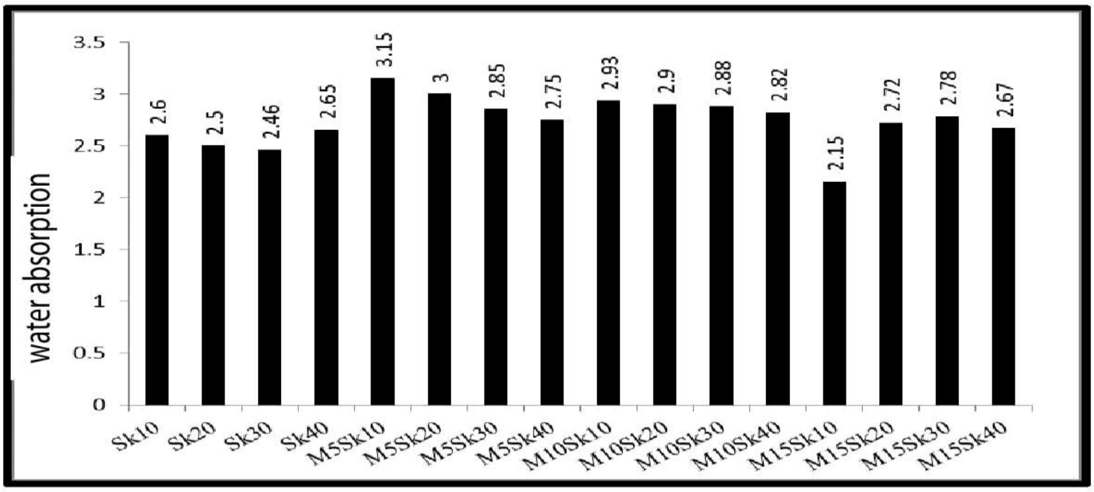


**Figure 8 - water absorption of samples in the first and second phases**

**Conclusion**

Based on the experiments, the following results were obtained:

1. The use of slag and micro-sio$_2$ with little effect on increasing strength and reduce water absorption so that the increase in slag, micro-sio$_2$

was more than the additive effect in samples with low percentage of slag, micro-$sio_2$ has less impact on the development of strength.

2. Use of fixed micro-$sio_2$ in samples containing slag reduces the water absorption and water absorption increases the slag reduction more, the highest water absorption was for M5Sk10 and lowest water absorption was for sample M15Sk10.

3. The flexural strength was related to sample M15Sk10 and least strength was in sample M15Sk40 and generally the samples containing 40% slag in every plan is the lowest flexural strength among projects.

4. Fume at all levels and in all projects has been dramatically increases the compressive strength of concrete, so that all projects using micro-$sio_2$ concrete containing slag strength than they earn.

5. According to that slag is the waste, the only production costs for slag, is collection costs and the mill coast which in production, the production cost is far less than the cost of cement production.

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