Effect of Micro-Silica on Mechanical Strength of Concrete

Dev Raj Joshi[1], Kamal Bahadur Thapa[2]

[1]Department of Material Science & Engineering, Tribhuvan University, Institute of Engineering, Pulchowk, Lalitpur, Nepal

[2]Department of Civil Engineering, Tribhuvan University, Institute of Engineering, Pulchowk, Lalitpur, Nepal

Abstract: ***This paper investigate the variation in compressive strength and tensile strength of concrete by using micro-silica. Micro-silica is used in partial replacement of ordinary Portland cement (OPC) by weight at 0%, 2%, 4%, 6%, 10%. In this research M20 grade concrete was used in which material proportion was determined by design mix. Design mix by IS method was used for concrete cube and ACI design mix method used for Cylindrical sample to find out material proportion. Compressive strength test was carried out on 150mm concrete cube and tensile strength test was carried out on 100mm diameter & 200mm long cylinder by splitting test after 7, 14 and 28 days curing period. According to the experimental results, the compressive strength at 28 days ranged between 28.948MPa & 40.519MPa and Tensile strength at 28 days ranged between 2.707MPa & 5.361MPa. These indicate that 10% micro-silica used in replacement of OPC increases the compressive and Tensile strength significantly.***

Keywords: Micro-silica, Compressive strength, Tensile strength, Design mix

1. Introduction

Concrete is a most widely used building material which is a mixture of cement, sand, coarse aggregate and water. It can be used for construction of multistory buildings, dams, road pavement, tanks, offshore structures, canal lining. The process of selecting suitable ingredients of concrete and determining their relative amount with the objective of producing a concrete of the required strength durability and workability as economically as possible is termed the concrete mix design. The compressive strength of hardened concrete is generally considered to be an index of its other properties depends upon many factors e.g. quality and quantity of cement water and aggregates batching and mixing placing compaction and curing. The cost of concrete made up of the cost of materials plant and labor the variation in the cost of material arise from the fact that the cement is several times costly than the aggregates thus the aim is to produce a mix as possible from the technical point of view the rich mixes may lead to high shrinkage and cracking in the structural concrete and to evolution of high heat of hydration is mass concrete which may cause cracking. The actual cost of concrete is related to cost of materials required for producing a minimum mean strength called characteristic strength that is specified by designer of the structures. This depends on the quality control measures but there is no doubt that quality control adds to the cost of concrete. The extent of quality control is often an economical compromise and depends on the size and type of job nowadays engineers and scientists are trying to increase the strength of concrete by adding the some other cheap and waste material as a partial replacement of cement or as a admixture fly ash, micro silica, steel slag etc. are the few examples of these types of materials. These materials are generally byproducts from other industries for example fly ash is a waste product from power plants and silica fume and micro silica are the byproduct resulting from reduction of high purity quartz with coal or coke and wood chips in an electric arc furnace during production of silicon metal or ferrosilicon alloys. Micro silica can be used either as a densified or un-densified powder, a slurry, as a combination at the concrete mixer, or part of a factory-blended cement. The following are the chief applications of micro silica amorphous particles:

- As an additive for rubber and plastics.
- As strengthening filler for concrete and other construction composites.
- As a stable, nontoxic platform for biomedical applications.
- As an admixtures for concrete strengthening.

2. Literature Review

High performance concrete is a novel construction material with improved properties like higher strength and longer durability compared to conventional concrete. High Strength Concrete (HSC) is a type of HPC. (Kumar, et al., 2014) Appropriate use of mineral and chemical admixtures with better quality control leads to HSC. Extensive research work has also established that the addition of fly ash, rice husk, furnace slag and other similar materials to plain cement concrete improves its strength, durability, toughness, ductility and post-cracking load resistance. In this project, an attempt has been made to study effect of addition of micro-silica on the properties of concrete. The mix design of concrete is carried out. Effects of on the compressive and flexural strengths of concrete with varying water-cement ratios and 0%, 2%, 4%, 6% and 10% micro-silica replacement, are studied. (Mazloom, et al., 2004) It has been found that the compressive strength of concrete increases with increase in micro-silica content. However, micro-silica does some little affect flexural strength as much as it does to compressive strength. The density of concrete is also reduced with addition of micro silica. So it can be used in high strength but light weight concrete.

3. Material

3.1 Cement

Ordinary Portland Cement (OPC) 43 grade was used for this study. The cement was tested for its Normal consistency, initial and final setting time, specific gravity and its compressive strength. 29% normal consistency was found by Vicat's apparatus. Initial and final setting time was found 34 min and 612 min(10hr 12 min) respectively. The specific gravity of cement was determined according to the British Standard (BS 1377: Part 2) using the small pycnometer method.

3.2 Aggregate

The fine aggregate used was river sand passing by 4.75 mm sieve. The coarse aggregate was crushed with size 4.75 – 19 mm by sieve analysis. The specific gravity of coarse aggregate and fine aggregate (sand) was taken as 2.7 and 2.6 respectively for mix design.

3.3 Micro- Silica

Micro silica is a by-product of the manufacture of silicon metal and ferro-silicon alloys. The process involves the reduction of high purity quartz (SiO2) in electric arc furnaces at temperatures in excess of 2,000°C. Micro silica is a very fine powder consisting mainly of spherical particles or microspheres of mean diameter about 0.15 microns, with a very high specific surface area (15,000–25,000 m2/kg). Each microsphere is on average 100 times smaller than an average cement grain. At a typical dosage of 10% by mass of cement, there will be 50,000–100,000 silica fume particles per cement grain.

Figure 1: Amorphus Micro-Silica

4. Mechanism of Micro- Silica

Micro silica improves concrete through two mechanisms: (King, 2012 August).

4.1 Pozzolanic effect

When water is added to OPC (ordinary Portland cement), hydration occur forming two products, as shown below:

OPC + $H_2O \rightarrow$ CSH (Calcium silicate hydrate) + $Ca(OH)_2$

In the presence of micro-silica, the silicon dioxide from the micro-silica will react with the calcium hydroxide to produce more aggregate binding CSH as follows:-

$Ca(OH)_2 + SiO_2 + H_2O \rightarrow CSH$

The reaction reduces the amount of calcium hydroxide in the concrete. The weaker calcium hydroxide does not contribute to strength. When combine with carbon dioxide, it forms a soluble salt which will leach through the concrete causing efflorescence, a familiar architectural problem.

Concrete is also more vulnerable to sulphate attack, chemical attack and adverse alkali-aggregate reactions when high amounts of calcium hydroxide is present in concrete. (King, 2012 August).

4.2 Micro-filler effect

Micro-silica is an extremely fine material, with an average diameter 100 times finer than cement. At a typical dosage of 8% by weight of cement, approximately 100,000 particles for each grain of cement will fill the water spaces in fresh concrete. This eliminates bleed and the weak transition zone between aggregate and paste found in normal concrete. This micro-filler effect will greatly reduce permeability and improve the paste-to-aggregate bond of silica fume concrete compared to conventional concrete. (Nilforoushan, 2005)The silica react rapidly providing high early age strength and durability. The efficiency of micro-silica is 3-5 times that of OPC and consequently vastly improved concrete performance can be obtained.

5. Mix Design

Concrete mix design is the method of correct proportioning of ingredients of concrete, in order to optimize the above properties of concrete as per site requirements. In other words, we determine the relative proportions of ingredients of concrete to achieve desired strength & workability in a most economical way.

Mixture proportioning was carried out according to the current British mix design method (Department of Environment DOE) for Concrete Cubes and American Concrete Institute Method (ACI) for cylinder sample. The mixing proportion was 1: 1.623:2.638 (Cement: sand: Aggregate) with water cement ratio 0.45 for concrete cube by IS method and 1:1.9075:2.48 (Cement: sand: Aggregate) with water cement ratio 0.5 for cylinder by ACI method. Method (Department of Environment DOE) for Concrete Cubes and American Concrete Institute Method (ACI) for cylinder sample. The mixing proportion was 1:1.623:2.638 (Cement: sand: Aggregate) with water cement ratio 0.45 for concrete cube by IS method and 1:1.9075:2.48 (Cement: sand: Aggregate) with water cement ratio 0.5 for cylinder by ACI method.

6. Experimental Procedure

6.1 Sample Preparation

International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

In this study, Cube of size 150*150*150 mm^3 and Cylinder of size 100 mm diameter and 200 mm length was prepared by mixing cement and Aggregate (coarse and fine) according to Design Mix. The micro-silica was added to the mix by 0%, 2%, 4%, 6%, 10%, by weight of cement. For each micro silica content,3 samples of cube and 3 samples of cylinder are made. The total mixing time was 5 minutes then the samples were casted and left for 24 hours. After that samples were demoulded and placed in the curing tank until the testing time at the age of 7 days, 14 days, 28 days.

Figure 2: Cube and Cylinder sample

6.2 Testing Methods

The slump test was conducted to evaluate the workability of concrete. The compressive strength was done according to the relevant British Standard (BS EN 12390-3:2002) on a 150 mm concrete cube specimen. The compressive strength tests were performed to determine the load bearing capacity of blocks. The dry compressive strength were determined. For the dry compressive strength tests, the blocks aged 7, 14 and 28 days were transported from the curing and stacking area to the laboratory two hours prior to the test to normalize the temperature and to ensure that the block was relatively dry. The weight of each block was measured before the block was placed onto the compression testing machine such that the top and bottom as moulded, lied horizontally on a flat metal plate.

Figure 3: Compressive Strength Test Set-up

The block was than crushed and the corresponding failure load was recorded. The failure load was divided by the sectional area of the block to arrive at the compressive strength. Tensile Splitting test was carried out as specified in BS1881-117. Cylindrical sample of size 100mm diameter *200mm length were moulded and stored in water before testing for tensile splitting strength. The automatic universal testing machine is used for the test.

Figure 4: Tensile Splitting strength Test Set-up

Three similar samples were prepared by using different proportion of micro-silica. Total of 15 cylinder sample were cast and tested. The casting was made by filling each mould with freshly mixed concrete in two layer of 100 mm thickness using 25 mm diameter steel rod to give 35 strokes of the tamping rod on each layer.For the testing, sample was placed on the universal testing machine and supported longitudinally with hardboard packing strips carefully positioned along the top bottom of the plane of loading of the sample.

The tensile splitting strength was determined as shown below

$$Ft = \frac{2P}{\pi LD}$$

Where P is the maximum load at which failure occurs.

7. Result and Discussion

The 28 days compressive strength for M20 grade concrete for 0%, 2%, 4%, 6%, 10% is 28.948MPa, 32.948MPa, 34.889MPa, 36.993MPa, 40.519Mpa, respectively. The flexural strength after 28 days for same percentage of micro-silica is 2.707MPa, 3.291MPa, 4.246MPa, 4.618MPa, 5.361MPa. The compressive strength and flexural strength achieved at different curing period namely 7, 14 and 28 days are indicated in figure 5 and 6 for different proportion of micro-silica.

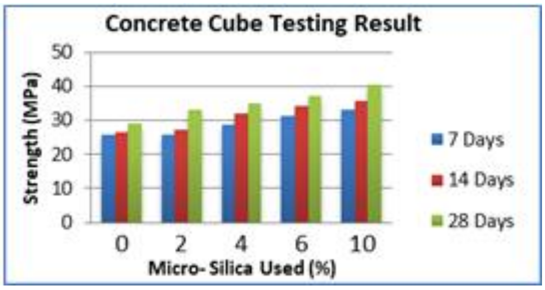

Figure 5: Compressive strength of cube

The compressive strength of M20 grade achieved at different ages for concrete cube of size 150 mm are also presented in bar chart in figure 5. From the figure, it is clear that as the increase of micro-silica, the strength of concrete cube increases.

Table 7: Compressive strength ratio of 28 days at different proportion of micro-silica used

Micro-Silica Used	0%	2%	4%	6%	10%
M20 Grade	1	1.14	1.21	1.28	1.40

Table 8: Flexural Streength Test ratio of 28 days at different proportion of micro-silica ussd

Micro- Silica used	0%	2%	4%	6%	10%
M20 Grade	1	1.19	1.57	1.71	1.98

Compressive strength and Flexural strength of M20 grade concrete achieved by using different proportion of micro-silica at 28 days as a ratio of strength without using micro-silica is reported in table 7 and table 8. From the table it can be seen that 2% micro-silica increase compressive strength by 1.14, by 4% micro-silica increase by 1.21, by 6% micro-silica increase by 1.28 and by using 10% micro-silica strength increase by 1.40 times.

From both the table 7 and 8, it is clearly seen that the use of micro-silica increase rapidly the flexural strength in comparison to compressive strength.

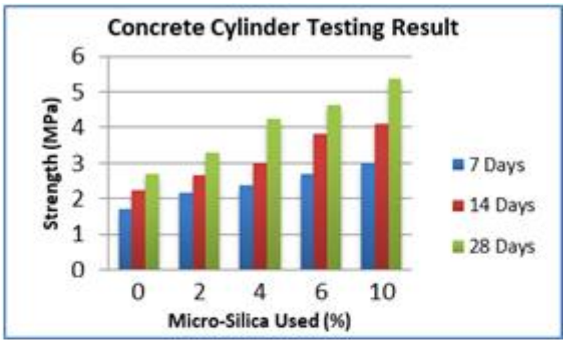

Figure 6: Tensile Strength result

The flexural strength of M20 grade concrete achieved at different age for concrete cylinder of size 100mm diameter and 200mm length are also presented in Bar Chart in figure 6. From the figure, it is clear that as the increase of micro-silica content, the strength of concrete in bending also increases.

From table 8, flexural strength of M20 grade concrete achieved by using different proportion of micro-silica at 28 days as a ratio of strength without using micro-silica seen that 2% micro-silica increase flexural strength by 1.19, by 4% micro-silica increase by 1.57, by 6% micro-silica increase by 1.71 and by using 10% micro-silica strength increase by 1.98 times.

Table 5: Summary Result

Concrete Cube Testing Result						
SN	Micro- Silica used (%)	Curing Period (Days)			Unit	Remarks
		7	14	28		
1	0	25.630	26.644	28.948	MPa	
2	2	25.778	27.244	32.948	MPa	
3	4	28.815	31.926	34.889	MPa	
4	6	31.111	34.296	36.993	MPa	
5	10	33.185	35.630	40.519	MPa	
Concrete Cylinder Testing Result						
SN	Micro- Silica used (%)	Curing Period (Days)			Unit	Remarks
		7	14	28		
1	0	1.699	2.240	2.707	MPa	
2	2	2.155	2.643	3.291	MPa	
3	4	2.378	3.025	4.246	MPa	
4	6	2.696	3.822	4.618	MPa	
5	10	3.025	4.119	5.361	MPa	

From the above table it can be clearly seen that, the compressive strength and flexural strength of M20 grade concrete by using micro-silica in replacement of cement significantly affect. 10% of micro-silica used in replacement of cement achieves 40Mpa compressive strength of M20 grade concrete. The effect of micro-silica in flexural strength of concrete is 1.98 time normal concrete at 28 days.

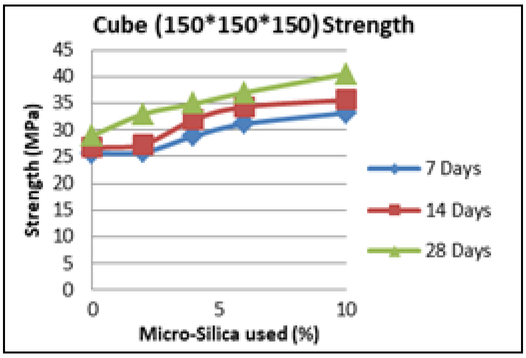

Figure 7: Effect of micro-silica on concrete compressive strength

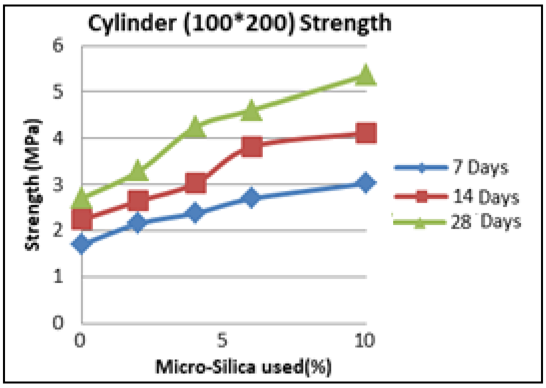

Figure 8: Effect of micro-silica on concrete flexural strength

It is seen that strength of concrete in compression and tension are closely related, but the relationship is not of the type of proportionality. Higher compressive strength concrete shows higher tensile strength. Variation of compressive and flexural strength with respect to age and percentage of micro-silica of M20 grade concrete is depicted in the figure 7 and figure 8.

8. Conclusion

Based on this study carried out on the strength behavior of M20 grade concrete using micro silica as an additive, the following conclusion are drawn:

The seven days compressive strength by using 0%,2%,4% micro-silica does not change significantly but for 6% and 10% strength increases by 1.2 and 1.3 times of without using micro-silica.

Tensile strength of concrete increases smoothly by increasing percentage of micro-silica. 28 days tensile strength of 10% micro-silica content is almost double of simple concrete.

The compressive strength of the concrete with 10% micro-silica has been increased significantly.

References

[1] Anon., 1959. IS 516:1959 Methods of Tests for Strength Of Concrete.
[2] Anon., 1970. IS 383:1970 Specification for Coarse And Fine Aggregates From Natural Source For Concrete
[3] Anon., 1989. IS 10262:1989 Recommended Guidelines for Concrete Mix Design.
[4] Anon., 1999. IS 5816:1999 Splitting Tensile Strength Of Concrete-Method of Test.
[5] Anon., 2000. IS456:2000 Plain and Reinforced Concrete Code of Practice.
[6] Anon., n.d. ACI Standard: 211.1 Recommended Practice for Selecting Proportions Of Concrete.
[7] Davraz, M. & Gundez, L., 2005. *Engineering properties of amorphous silica as a new natural pozzolana for use in concrete*, Suleyman Demirel University Isparta Turkey: Pumice research and Application center.
[8] FRIEDE, B., November 15-18, 2006 . *Microsilica–Characterization of An Unique Additive*, Issue São Paulo – Brazil, p. 135.
[9] King, D., 2012 August. THE EFFECT OF SILICA ON THE PROPERTIES OF CONCRETE AS DEFINED IN CONCRETE SOCIETY REPORT 74, CEMENTITIOUS MATERIALS. *37th Conference on Our World in Concrete & Structures.*
[10] Kumar, A., Gupta, P. & Gupta, A. K., 2014. International Journal of Engineering Research and Applications. *Experimental Investigation of Influence of Micro Silica on High Strength Concrete Properties*, 29 March.
[11] Madhusudhan, T., March 2013. International Refereed Journal of Engineering and Science (IRJES). *Utilization of micro silica as partial replacement of OPC & SRC in Concrete*, 3(3), pp. 67-73.
[12] Mazloom, M., Ramezanianpour, A. A. & Brooks, J., 2004. Cement and Concrete Composites. In: Tehran: Department of Civil Engineering, Shahid Rajaee University, pp. 347-357.
[13] McDonald, J. E., March 1991. *REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM*, 3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199: DEPARTMENT OF THE ARMY Waterways Experiment Station, Corps of Engineers.
[14] Nilforoushan, M. R., 2005. *The effect of micro silica on permeability and chemical durability of concrete used in corrosive environment*, Volume 24.
[15] Sharma, U., Khatri, A. & Kanaungo, A., 2014. International Journal of Civil Engineering Research.. *Use of Micro-silica as Additive to Concrete-state of Art*, Volume 5, pp. 9-12.
[16] Vijay, A., Chandak, R. & Yadav, R., 2012. Effect of Micro Silica on The Strength of Concrete with Ordinary. *Research Journal of Enginnering Sciences*, Volume 1(3).
[17] Arpana “Rice Husk Ash-Admixture to Concrete”, 2nd national conference on Advances in concrete Technology, February 29-27,2004,pp.93-98
[18] Gemma Rodriguez de Sensale “Strength Development of Concrete with Rice-Husk Ash”, cement & Concrete Composites 28,2006,pp.17-22.
[19] British Standard Institution (1983). Methods for Determination of Compressive Strength of concrete Cubes BS 1881, Part 116, British Standard Institution London.
[20] Malhotra, V.M. and Mehta, P.K.(2004). Pozzolanic and Cementitious Material. London: Taylor & Franics.