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The Use of Nanosilica for Improving of Concrete Compressive Strength and Durability

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Abstract. The development of construction materials technology, particularly concrete is growing very rapidly in the presence of nanotechnology. One material that deserves the attention of researchers is nanosilica. Silica has been used on concrete, starting from silica sand as a filler to microsilica (silica fume) as a reactive pozzolan. Based on previous research, silica fume is proven effective to improve the mechanical properties and durability of concrete. A novel nanotechnological process allows producing amorphous nanosilica with high reactivity from locally available silica sand. In this study a locally available nanosilica is used on mortar and concrete thereby limiting the use of commercial nanosilica materials from semiconductor industry waste. To obtain sustainable concrete, the mix is design to have high strength as well as low permeability using as much possible local sources. This study also make use of commercial, regular silica fume combined with the locally produced nanosilica. The results show that combined use of nanosilica with silica fume can increase the compressive strength and durability.

Introduction

Nanotechnology has been applied to concrete production and has the potential of improving the performance of concrete. It has been shown to increase the mechanical and durability properties of concrete leading to development of novel and sustainable materials [1,2,3]. However, the application of nanotechnology in concrete technology should go along with the availability of local materials [2]. One interesting material to study is nanosilica produced from silica sand. Previous research on concrete using nanosilica has pointed out that improved workability and strength of concrete or mortar are to be expexted [3,5,7]. The use of nanosilica dan microsilica as partial replacement of cement have some advantageous effects on concrete performance [4]. Nano-SiO_2 was also found to be more efficient in enhanching strength than silica fume [4,5]. Nanosilica can improve the performance of cement-based materials matrix through increased production of CSH gel due to pozzolanic reaction and reduced amount of $Ca(OH)_2$. It can also act as micro and nano filler [3]. Previous studies using nanosilica, generally used commercial nanosilica such as Cembinder 8 made by Akzo Nobel Chemical GmbH, CS 15, CS 30 C from Bayer, ADCS 5, ADS 20 from Nyacol nano technologies [4,6,7,8,9]. Meanwhile, the nanosilica used in this study is a powder obtained from a process of extraction of silica sand (natural ingredients). This study aims to investigate the effect of adding nanosilica alone and nanosilica and silica fume combined, on the compressive strength concrete and permeability and chloride penetration resistance. The later is tested as indicators of durability performance.

Materials And Metodology

Materials used were cement type I, silica fume ex Sika dan nanosilica ex Indonesia. The nanosilica used has been processed to particle sizes down to 40-80 nm. The coarse aggregate has a maximum size of 14 mm and available in two ranges, 5-10 mm and 10-14 mm.

Coarse aggregate used has a compressive strength of 184 - 232 MPa. Chemical compositions of Cement type I, silica fume, nanosilica are shown in Table 1.

Table 1. Chemical analysis materials

Composition	Cement type I	Silica fume	Nanosilica
SiO_2	19.0 -21.0	87.74	99.60
Al_2O_3	4.0 -6.0	0.720	-
Fe_2O_3	2.5 – 3.5	1.63	0.08
CaO	62.0 – 67.0	0.520	-
MgO	1.0 – 4.0	-	-
C_3S	55- 64	-	-
C_2S	9 - 20	-	-
C_3A	7- 11	-	-
C_4AF	9-11	-	-

The specimen are demolded at 24 hour and then cured in room temperature. The compressive strength test follows ASTM C 39/C 39M-04a with the specimen size 100 mm x 200 mm. Testing was peformed for concrete at ages 1, 3, 7, 28 days. Meanwhile, the permeability test folows DIN 1048 Part 5 with specimen size 200 mm x 200 mm x120 mm. Rapid Chloride permeability test (RCPT) follows ASTM C 1202. An RCPT specimen has a nominal diameter of 100 mm and thickness of 50 mm cut from the center of a cylindrical sampel. Then, SEM (*Scanning Electron Microscope)* images was also taken to study concrete microstructure.

Mix designs are provided in Table 2. The percentages of nanosilica by weight of cement are: 3% (NS3), 5% (NS5), 10% (NS10), 15% (NS15). In mixes containing silica fume the percentages are: 3% nanosilica + 5% silica fume (NS3-SF5), 5% nanosilica + 5% silica fume (NS5-SF5), 10% nanosilica + 5% silica fume (NS10-SF5), 15% nanosilica + 5% silica fume (NS15-SF5). Water to binder ratios vary from 0.23 to 0.3. An admixture called viscocrete is used and varied to maintained a slump of around 5 cm.

Table 2. Mix Design

Mixture Proportions Kg/m^3	Ref.	NS3	NS5	NS10	NS15	NS3 -SF5	N5- SF5	NS10- SF5	NS15- SF5
Cement	900	900	900	900	900	900	900	900	900
Silica fume	120	-	-	-	-	45	45	45	45
Nanosilica	-	27	45	90	135	27	45	90	135
Ratio water /binder	0.23	0.23	0.23	0.26	0.3	0.24	0.25	0,27	0.3
Sand	638	638	638	638	638	638	638	638	638
Coarse aggregate	1094	1094	1094	1094	1094	1094	1094	1094	1094
Viscocrete 10 ex Sika	15	15	15	20	22	15	15	21	24

In preparing the mixes, the following mixing procedure is used to uniform and well mixed concrete [10]. Steps that are done include: mixing coarse aggregate + 50% water + 50% cement for 30 sec to 1 min, adding 50% cement + 25% water + superplasticier + fine aggregate and mixing for 2 min, finally, adding 25% water and mixing for 3 min.

Results And Discussion

The result for compressive strength is shown in Fig.1. The usual age effect is readily identified. From the figure, adding nanosilica alone is seen to improve the strength. However, higher percentages do not seem to have a marked effect. Nanosilica addition of more than 10% does not seem to be effective. The highest 28-day compressive strength is obtained for the mix with 10% nanosilica + 5% silica fume (NS10-SF5), which is 132 MPa. The reference mix gives a value of 91 MPa. Thus, there is an increase of 45% . Uses of nanosilica in NS15 dan NS15-SF5 results in compressive strenght decrease of respectively, 47% dan 33%. This is thought to be caused by the agglomeration effect .

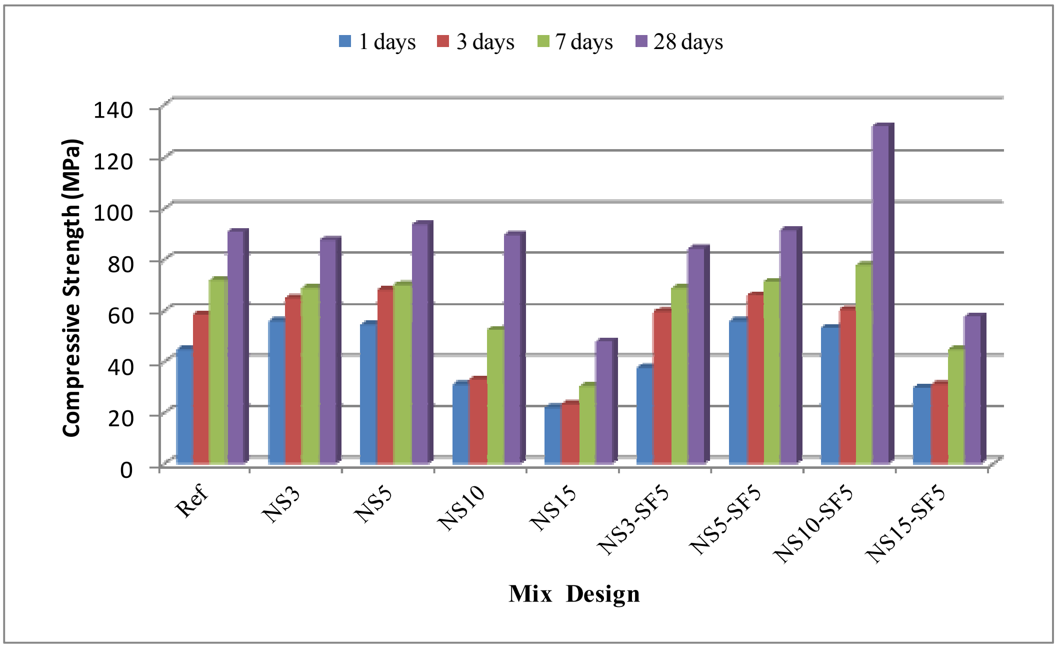

Fig. 1: Result of Compressive Strength

The result of RCPT is given in Fig. 2. The lowest RCPT value is 45 coulombs, which indicates the high resistance of concrete against chloride ion penetration (negligible chloride related durability issue when RCPT < 100 coulombs). Figure 3 shows the result of permeability test fllowing DIN 1048 Part 5. The lowest water permeation of 0,6 cm is obatined from mix NS10-SF5. The reference mix gives a value of around 1 cm. For information, normal concrete usually has a water permeation of around 5 cm..

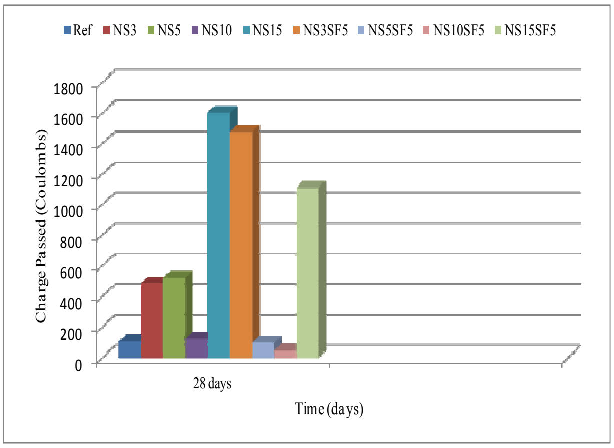

Fig. 2 : Result of RCPT

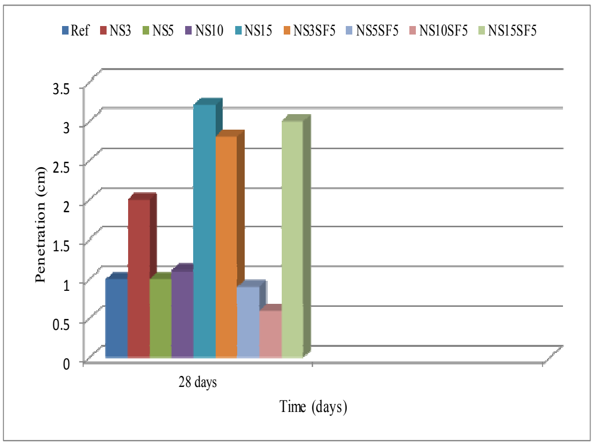

Fig. 3: Result of Permeability

Figure 4 shows the result of SEM for the reference mix and NS5. Morphologies of Calcium Hydroxide (CH) dan Calsium Silicate Hydrate (CSH) can be identified from the images. The images generally indicate some nanosilica readily react with CH to produce new forms of CSH which leads to concrete having improved compressive strenght and durability

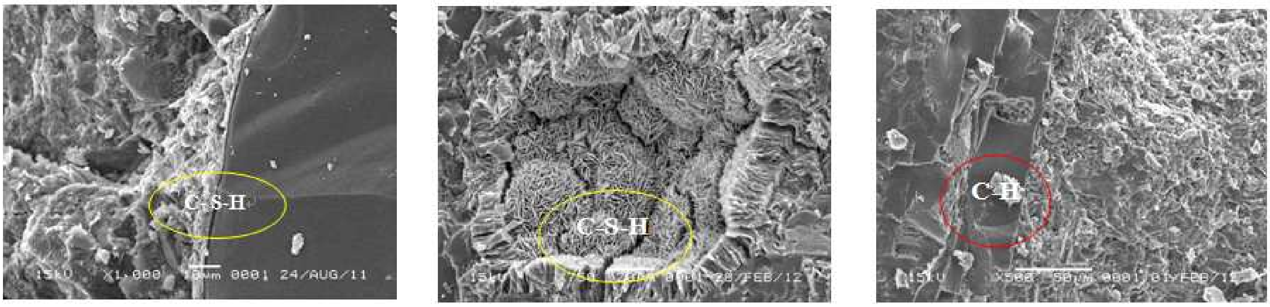

Fig 4. SEM of C-S-H and C-H, Ref and NS5

Conclusion

1. The combined use of nanosilica with silica fume can effectively increase the compressive strength and durability of concrete.
2. To avoid the agglomeration effect, this study suggests the percentage of nanosilica in the concrete to be not more than 10%.
3. SEM images gives helpful information and insight to appearances C-H and C-S-H morphologies.

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