PAPER • OPEN ACCESS

Performance of High Early Strength Concrete (HESC) using Different Superplasticizer

To cite this article: Y Sunarno *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1117** 012034

IOP Conf. Series: Earth and Environmental Science 1117 (2022) 012034 doi:10.1088/1755-1315/1117/1/012034

Performance of High Early Strength Concrete (HESC) using Different Superplasticizer

Y Sunarno[1], M W Tjaronge[2], R Irmawaty[2], A B Muhiddin[2]

[1]Doctoral Student, Civil Engineering Department, Universitas Hasanuddin, Makassar, Indonesia.
[2]Civil Engineering Department, Universitas Hasanuddin, Makassar, Indonesia.

email: yohanssunarno@gmail.com

Abstract. High Early Strength Concrete (HESC) is one type of high-performance concrete. HESC production requires high-quality materials and additives, namely chemical admixture type C (superplasticizer) to get high performance. This study aims to obtain a HESC mix design using a superplasticizer with the best performance. The 3 variations of HESC are made by adding a superplasticizer to a mixed concrete with the same dosage but from 3 different manufacturers, namely HESC-1, HESC-2, and HESC-3. Specimens performance consisted of tests for both fresh concrete and hardened concrete. The fresh concrete was tested by the slump, and the hardened concrete was tested by density and compressive strength tested at the age of 12 hours, 14 hours, and 3 days on cylindrical specimens measuring 100 mm x 200 mm which have been cured by water curing. Based on the test results, it was found that the average slump values in HESC-1, HESC-2, and HESC-2 were (cm): 64.0, 69.5, and 70.5. This shows that all HESC specimens are categorized as Self Compacting Concrete. According to the results of the density test on all specimens ranging from 2382 to 2436 kg/m3, all specimens are included in normal-weight concrete. With the initial compressive strength value of HESC at the age of 14 hours in the range of 21.0 to 24.9 Mpa, it can be concluded that all HESC specimens meet the requirements of High Early Strength Concrete, where HESC-3 is the best performance one.

1. Introduction

High early strength concrete (HESC) is one type of high-performance concrete that can achieve the quality of structural concrete with a compressive strength of > 21 MPa at 24 hours after site pouring [1]. High early strength concrete (HESC) reaches the designed strength in a short time. High strength at an early age is desirable for high-speed cast-in-place construction, cold weather construction, quick repairs of rigid pavements to reduce traffic downtime, fast-track pavement, and other uses. HESC can develop by using ordinary concrete constituents, chemical admixtures, and specific concrete engineering. Some methods used to achieve HESC are as follows: using high early strength cement (cement type III), increased cement content, low water-cement ratio, added chemical admixture, and steam curing [2] [3].

Chemical admixture on concrete has an important function to improve the performance of concrete. Its use can increase the characteristics of fresh concrete, assurance the quality of concrete at the time of mixing, delivery, casting, and curing, as well as overcome certain crises that may arise during the construction process, while reducing its production costs. ASTM C494 [4] provides standards for seven types of chemical admixture that differ according to their characteristics. One of which is chemical admixture type F (superplasticizer) which has a function as water-reducing and high-range admixtures

Superplasticizers are used to increase the fluidity of concrete without adding water to the mixed concrete. These molecules physically separate the cement particles by counteracting their attractive forces by steric and/or electrostatic forces. So that concrete is easier to work on at the time of pouring concrete. The workability of concrete can be maintained for a long period of time (1-2 hours or more), thus facilitating the process of casting, from transportation, pouring, pumping, compaction, and casting [5]. The availability of superplasticizers on the market today is very much, but it is still necessary to conduct research and development to meet the need for more complex concrete technologies [6][7]. Some of the most widely used type superplasticizers related to the improvement of water reducing ability are (a) Lignosulfonate (LS), with a limited water reduction ability of about 10%, used mainly in formulations to improve workability retention in ready mix applications. (b) Sulfonated naphthalene formaldehyde condensates (PNS), also known as poly naphthalene sulfonates (PNS), have a weak interaction with clay minerals with a water reduction ability of up to 30%. (c) Polymelamine sulfonates (PMS) and sulphonate formaldehyde condensate (PMS) with the ability to reduce water content by more than 20-30%. (d) Synthetic polymers, such as polycarboxylates and acrylic copolymers (PCEs), have a versatile chemical structure and can achieve water reduction of up to 40%, but have a low tolerance to clay minerals [7].

This study aims to get a mixed design of HESC which the best performance. HESC is produced by adding a superplasticizer with the same dose but comes from 3 different factories, namely HESC-1, HESC-2, and HESC-3. HESC performance consisted of tests for both fresh concrete and hardened concrete. The fresh concrete was tested by the slump, and the hardened concrete was tested by density and compressive strength tested on cylindrical specimens measuring 100 mm x 200 mm which have been cured by water curing. Testing of hard concrete is carried out at the age of 12 hours, 14 hours, and 3 days.

2. Material and Methods

2.1 Chemical and Physical Characteristics of Ordinary Portland Cement (OPC)

Testing the physical characteristics of ordinary portland cement (OPC) is carried out to obtain its physical properties as a reference in the manufacture of concrete mix-design. Chemical characteristics testing was carried out to analyze the chemical composition of OPC. The chemical characteristics testing carried out is in the form of XRF (*X-Ray Flourence*) testing which aims to determine the chemical content of the material being tested in the form of elements that make up the material used to produce concrete [8] [9]. Table 1 shows the tested results of OPC's physical and chemical characteristics.

Table 1. The Chemical and Physical Characteristics of OPC

PROPERTIES	Unit	Test Methode	Result	Specification
Chemical Properties				
MgO	%	ASTM C114	1.49	Max. 6.0
SO_3 if C_3A ≤8.0	%	ASTM C114	2.29	Max. 3.5
Loss of Ignition	%	ASTM C114	2.47	Max. 5.0
Insoluble residue	%	ASTM C114	1.24	Max. 3.0
Equivalent Alkali (Na_2O+0.658 K_2O)	%	ASTM C114	0.38	-
Physical Properties				
Fineness/Blaine meter	m^2/kg	ASTM C204	338	Min. 280
Autoclave expansion	%	ASTM C151	0.23	Max. 0.80
Time of setting (Vicat test)				
- Initial Set	Minute	ASTM C191	112	Min. 45
- Final Set	Minute	ASTM C191	256	Max. 375
Compressive strength				
- a. 3 days	kg/cm^2	ASTM C109	196	Min. 135
- b. 7 days	kg/cm^2	ASTM C109	251	Min. 215
- c. 28 days	kg/cm^2	ASTM C109	364	Min. 300
False Set, final penetration	%	ASTM C451	84.02	Min. 50
Air Content	% volume	ASTM C185	3.30	Max. 12

Tested result of the physical and chemical characteristics of cement was carried out to determine the feasibility of cement used as a binding material in this study. The quality of OPC greatly affects the quality of the concrete produced [10]. Based on the test results of the physical characteristics of OPC in Table 1 shown, it can be seen that the OPC used meets the specifications of ASTM C150 [11].

2.2 Physical Characteristics of Aggregate

Table 3 shows the physical characteristics of coarse aggregates and fine aggregates. The coarse aggregate used is crushed stone which is produced by a stone crusher that uses raw materials derived from Bili-bili, Gowa Regency, South Sulawesi. It can be seen that the physical characteristics of the coarse aggregate are used to meet the specification of ASTM C33 [12]. The fine aggregate used is silica sand from the Pinrang river, South Sulawesi Indonesia. From table 3 it can be seen that the physical characteristics of the fine aggregates used to meet the specification of ASTM C33 [12].

Table 2 Physical Characteristics of Aggregate

Properties	Coarse Agg	Fine Agg
Colloid Content [%]	0.76	4.80
Fineness Modulus	6.99	3.01
Water absorption [%]	1.20	3.02
Moisture Content [%]	0.9	6.20
Specific Gravity (SSD)	2.61	2.58

2.3 *Characteristics of Superplasticizer*

The chemical admixture used in this study is a type of chemical admixture type F (superplasticizer) which has a function as a water-reducing and high-range admixture. This study uses a type of superplasticizer with 2 different product bases: Carbolic Acid Copolymer and Modified polycarboxylate in water from 3 different factories, namely superplasticizer-1, superplasticizer-2, and superplasticizer-3. Table 3 shows the characteristics of the superplasticizer used.

Table 3 Characteristics of Superplasticizer

Properties	Carboxylic Acid Copolymer	Modified polycarboxylate in water	
	Superplasticizer-1 (Sp-1)	Superplasticizer-2 (SP-2)	Superplasticizer-3 (Sp-3)
Density [kg/l]	1.10 ±0.05	1.06 ± 0.01	1.08 ± 0.02
Water reducing [%]	-	up to 25	up to 40
Dosage [%] of binder	0.3 - 2.0	0.8 - 2.0	0.8 – 2.0
Appearance	Dark brown liquid	Turbid yellowish liquid	Brown liquid

2.4 *Mixed Design*

The mixed design is made consisting of 3 variations of superplasticizer added to the mixed concrete. HESC-1 uses superplasticizer-1 (Sp-1), HESC-2 uses superplasticizer-2 (Sp-2), and HESC-3 uses superplasticizer-3 (Sp-3). The method of adding admixture is by mixing the liquid admixture into the water, stirring until homogeneous then adding it to the wet concrete mix. The dosage of admixture according to the technical data sheet of each product (table 3) is based on the percentage of the total weight of binder (cement). The HESC mixed design made in this study is in Table 4 below:

Table 4. HESC Composition (per 1 m^3)

Code	OPC (kg)	CA (kg)	FA (kg)	Water (kg)	Sp-1 (ltr)	Sp-2 (ltr)	Sp-3 (ltr)
HESC-1	580	740	1020	135	6.96	0	0
HESC-2	580	740	1020	135	0	6.96	0
HESC-3	580	740	1020	135	0	0	6.96

2.5 *Fresh Concrete Testing*
Workability testing was carried out by slump testing on fresh concrete according to ASTM C1611 standard [13], as shown in Figure 1.

Figure 1 Slump test on fresh concrete.

Figure 2 Cylindrical spesimen 100x200 mm

The weight and compressive strength tests were carried out on hard concrete at the age of 12 hours, 14 hours, and 3 days in the form of cylindrical specimens 100 mm x 200 mm which had been treated with water curing as Figure 2 according to ASTM C31 [14].

2.6 *Compressive Strength Test of Concrete*
The test method of compressive strength of cylindrical test refers to ASTM C39 [15] including the preparation and testing. At the preparatory stage follow the following procedure: (a) The test object is taken from the soaking bath. (b). Cleaning adhering dirt with a wet cloth. (c). Determine the weight and size of the test object. (d). Coating the upper and lower surfaces of the test object with sulfur mortar/capping (e). the test object is ready to be tested. After that, it is continued with the testing stage with the following procedure: (1). Placing the test object on the press machine in a centrist manner. (2). Running the press machine with an additional load between 2 to 4 kg /cm^2 per second. (3). Carry out loading until the test object becomes failure. (4). Record the maximum load that occurs during the inspection of the test object. (5). Drawing/documenting the shape of the damage to the test object. (6). Record the state of the test object. (7). Calculate the compressive strength of concrete, and the magnitude of the load of the unity of the area according to equation 1.

$$Fc = P/A \qquad \ldots\ldots (1)$$

Fc is the compressive strength of concrete (MPa)
P is the maximum load (N)
A is the surface area of the test object (mm^2)

3. Result and Discussion

3.1. Fresh Concrete Behaviours

From Table 5 can be observed the values of the results of slumps tested of all the mixed concrete. Based on the data from the slump test results on each mixed concrete, the average slump values of HESC-1, HESC-2, and HESC-3 were 64.0 cm, 69.5 cm, and 70.5 cm. This indicates the behavior of all the resulting HESC mixtures categorized as SCC (Self Consolidating Concrete) [16] [17]. HESC-3 has the highest slump value compared to other specimens because based on the admixture characteristics (table 3), the water reducer ability of Sp-3 is the highest, which is up to 40%. So with the same water content HESC-3 has the highest slump. From visual observations, it can be seen that the fresh concrete mixture from each mixture is adhesive: no segregation or bleeding occurs.

Table 5 Slump Tested Results

Specimen	Slump (Cm)		
	Max	**Min**	**Average**
HESC-1	65.0	63.0	64.0
HESC-2	70.0	69.0	69.5
HESC-3	72.0	69.0	70.5

3.2. Density and Visual Observation of Hard Concrete.

Based on Figure 3 shows that the density of HESC ranges from 2382 to 2436 kg/m^3. HESC-1 has the smallest density value with values (kg/m^3) at the age of 12 hours, 14 hours, and 3 days, respectively, namely 2382, 2383, and 2389. While in HESC-2 the density value (kg/m^3) is 2420, 2421, 2424. And the density value of HESC-3 (kg/m^3) is 2424, 2427, and 2436. Based on the density value, all HESC specimens are categorized as normal-weight concrete typically. According to ACI 318-11 [18], normal-weight concrete is concrete that has a density of 2155 kg/m^3 to 2560 kg/m^3. The density value increases with the age of concrete.

Based on visual observation of the hard concrete of all HESC specimens, it was found that the surface of the HESC specimen was smooth, flat, and shiny which showed that all types of superplasticizers used were well compatible with OPC so that the hardening process was good, in addition, there was no bladdery appearance in the specimens even though in the casting there was no vibrator used, this shows that Self Consolidating Concrete (SCC) behavior applies to all HESC specimens.

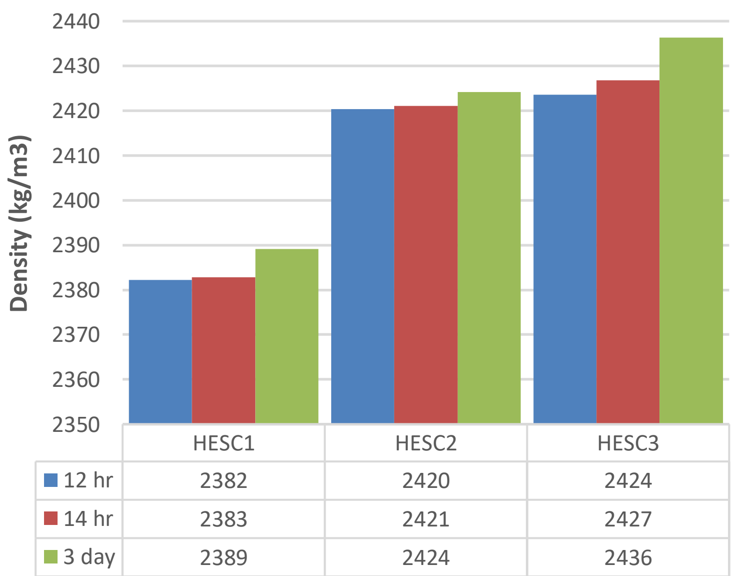

Figure 3 Density

3.3. Compressive Strength Results

Figure 4 showed compressive strength results at the age of 12 hours, 14 hours, and 3 days in each specimen variation. The compressive strength test results for HESC-1 are (MPa): 17.4, 21.0, and 34.0. In HESC-2 is (MPa): 21.8, 24.2, and 43.2. And for HESC-3 is (MPa): 21.6, 24.9, and 39.1. HESC-1 had the lowest average compressive strength value compared to other HESCs at each age, while HESC-2 specimens had the highest average value. An initial compressive strength test value of 14 hours on all HESCs above 21 Mpa shows that all HSCE specimens meet the requirements of High Early Strength Concrete (HESC) [1]. The highest compressive strength at the age of 14 hours HESC-3, this is influenced by the characteristics of the admixture used (Sp-3) which is the highest water reduction ability.

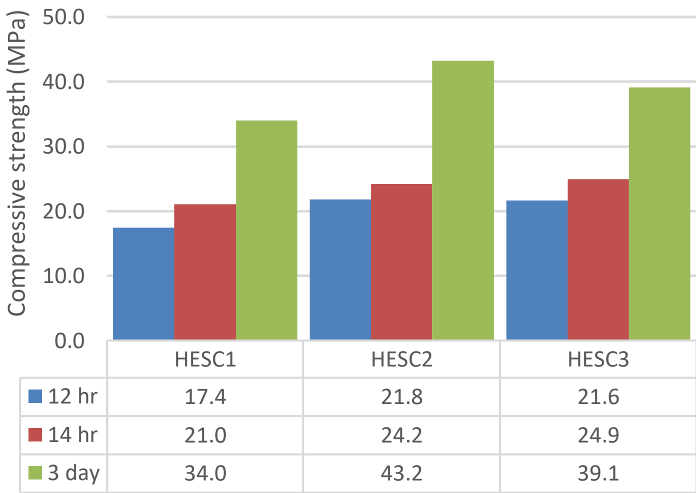

Figure 4. Compressive strength value of specimens against curing age

Figure 5 shows the percentage of initial compressive strength at the curing age of 12 hours, 14 hours, and 3 days against compressive strength at the age of 3 days in each specimen variation. The percentage values of compressive strength on HSCE-1 are (%): 51.2, 61.9 and 100.0. And HSCE-2 are (%): 50.4, 56.0, and 100.0. Then on HSCE-3 are (%): 55.3, 63.7 and 100.0. Based on Figure 5, it can be seen that the initial compressive strength value of the HSCE-1 is the lowest both at each concrete age, while HESC-2 has the highest percentage.

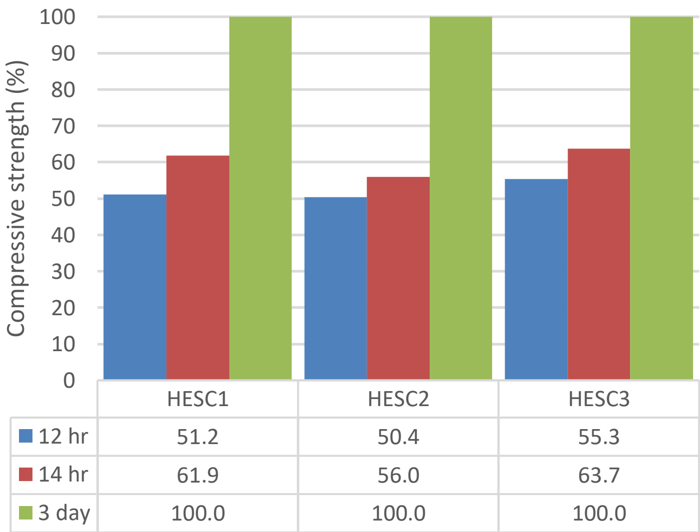

Figure 5. Percentage of compressive strength against 3 days age

4. Conclusions

Based on the density test results, it can be concluded that the density of all specimens can be categorized as normal-weight concrete typically according to ACI 318-11. Meanwhile, the results of slump testing on fresh concrete show the behavior of the HESC produced is included in the category of SCC (Self Consolidating Concrete). And based on the compressive strength results of all HSEC at a lifespan of 14 hours greater than 21 Mpa, all HESC specimens meet the requirements of the High Early Strength Concrete (HESC) category. HESC-3 has the highest compressive strength results at 14 hours of age. Visual observation of hard concrete on HESC shows that surface of specimens has a smooth, flat, and shiny surface indicating that all superplasticizers used in this study have good compatibility with OPC.

References

[1] Yasin, A.K., R Bayuaji, R., Susanto, T.E., 2017. *A review in high early strength concrete and local materials potential*, IOP Conf. Series: Materials Science and Engineering 267 (2017) 012004. doi:10.1088/1757-899X/267/1/012004EPRA
[2] Reddy, B. N., Naqash, J.A., 2020. *Review on Early Strength Concrete*. International Journal of Multidisciplinary Research (IJMR) -Volume: 6 | Issue: 12. DOI: 10.36713/epra2013
[3] Ananyachandran P., Vasugi, V. 2017. *Review on High Early Strength Concrete*. International Journal of Civil Engineering and Technology (IJCIET) Volume 8, Issue 7, July 2017.
[4] ASTM C494, *Standard Specification for Chemical Admixture for Concrete*, 2017
[5] Gelardi, G., Flatt, R.J., 2016. *Working mechanisms of water reducers and superplasticizers. Science and Technology of Concrete Admixtures*. Elsevier, (Chapter 11), pp. 257e278.
[6] Yaroshevskiy V. V., Kononenko A. M., Rodionov A .V., Saginov A. S. and Kwon S. S., 1986 *Complex admixture for early strength filling mixture*, Cert. of Auth. No. 1234380
[7] Perfilov V. A, 2005. *Complex admixture for early strength mixture*, RF Invent. Pat. No. 2258049
[8] Sunarno Y., Tjaronge M. W. and Irmawaty R. 2020. *Preliminary study on early compressive strength of foam concrete using Ordinary Portland Cement (OPC) and Portland Composite Cement (PCC)*. IOP Conf. Ser.: Earth Environ. Sci. 419.
[9] Sunarno Y., Tjaronge M. W., Irmawaty R. and Muhiddin A.B. 2022. *Unit Weight of Foam Concrete Containing Blended Cement and Fly Ash*. Jurnal Teknik Sipil & Perencanaan 24 (1) (2022) p 36 – 41.
[10] Rangan P.R., Tumpu M., Caroles M., Mansyur. 2021. *Compressive Strength of High-strength Concrete with Cornice Adhesive as a Partial Replacement of Cement*. IOP Conference Series: Earth and Environmental Science, Volume 871, Issue 1, id.012006, 7 pp
[11] ASTM C150, *Standard Specification for Portland cement*, 2012
[12] ASTM C33, *Standard Specification for Concrete Aggregate*, 2012
[13] ASTM C1611, *Standard Test Method for Slump of Self Consolidating Concrete.* 2021
[14] ASTM C31, *Standard Practice for Making and Curing Concrete Test Specimens in the Field*, 2019.
[15] ASTM C39, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*, 2012
[16] Okamura H., Ouchi M., 2003. *Self Compacting Concrete. Journal of Concrete Technology*. Vol 1 No.1, 5-15
[17] ACI 237R-07, *Self-Consolidating Concrete*, 2007.
[18] ACI 318-11, *Building Code Requirements for Structural Concrete and Commentary*, 2011.