Optimisation of Compressive Strength of Fast Track Concrate using Superplasticizer and Accelerator as Bridge Slab of Upper Structure

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Abstract

Fast track concrete is designed to accelerate the construction process, particularly in casting process. This study aims to determine the optimal early-age compressive strength of concrete applied to bridge decks, where flexural strength testing is conducted later. The used admixtures are superplasticizer (SP) and accelerator (AC). Those two admixtures are often applied on the site as combination to acquire fast hardening concrete, however not many scientific evidences support the using of them because of chemical compound effects so that this study is intended to enrich the references regarding them that are implemented in scaled model of bridge deck in order to test the actual behaviour. The dosages used are 0.8% and 1.2% of cement weight for superplasticizer, and 2.7% and 4.5% of cement weight for accelerator. Compressive strength testing is conducted at 6 hours, 1 day, 7 days, and 28 days after casting.

The mix combination used includes SP 0.8% – AC 2.7%, SP 0.8% - AC 4.5%, SP 1.2% - AC 2.7%, and SP 1.2% - AC 4.5%. The concrete design uses a strength of fc'30 MPa with cylindrical test specimens. The results show that compressive strength increases with age. Flexural strength testing is applied to a bridge deck slab measuring 1 x 0.5 x 0.1 m, tested at 3 days of age. The concrete mix uses fc'30 with an SP dosage of 1.2% and AC dosage of 4.5% of cement weight. In the flexural test, the average load-bearing capacity is 40 kN.

Keywords: fast track, accelerator, superplasticizer, bridge deck, compressive strength, flexural strength,

1. Introduction

Concrete is a crucial and fundamental component in construction, such as high story building, bridges, and other structures. It is composed of a mixture of fine aggregate, coarse aggregate, cement, and water. As the concrete technology advance, concrete continues developing to support construction processes. Some aspects need to be considered are strength, durability, and efficiency. Concrete performs good compressive strength but relatively poor in tensile. To achieve high quality concrete, additional materials are needed, like chemical compound to improve some concrete behaviors.

A common issue encountered in construction projects is the need for rapid construction that leads to quick completion. This is particularly relevant for bridge and road construction where the project duration can not be delayed because of high traffic demands. On the site, the using of any chemical compounds tend to provide some challenges such as mixture process that consume time and bleeding risk that may happen after the concrete are set. Therefore, to address those issues, some additional materials are needed to speed up the curing process while maintaining strength of the concrete itself. The concept of fast-track concrete is achieving both the time reducing of hardening process and strength quality. Fast-track concrete involve the use of superplasticizers (SP) and accelerators (AC) combinations to satisfy those characteristics.

Commonly, some SP applied on filed include polycarboxylic acid, naphthalene, amino, aliphatic, and melamine type [1,2]. Some previous researches stated that this chemical additive affect setting behavior and strength mechanism [3]. The overdose of SP on the mixture is unpreferable because it corresponds with the rate of slump and bleeding [4]. It also affects the improvement of strength that inherently linked with reduction of water to cement ratio [5].

The existence of AC is to shorten the hardening process because the fulfilled early strength target is extremely important for construction effectiveness and cost savings [6,7]. The addition of AC is commonly applied to concrete mixture to improve the compressive strength development as well as satisfy the designation demands [8,9,10]. This is because the proportion of AC leads to increasing of hydration rate, accelerating the precipitation of hydration products, as well as speeding up the initial crystallization [11,12,13].

In some previous studies, it is stated that the usage of chemical additive combination, which is two types of SP namely carbolic acid copolymer and polycarboxylate, resulted in different behaviour of concrete [14]. More specifically, another research stated that the existence of additional AC, ranged from 12 to 16 lt per m^3, affected in reduction of strength gap between 3 days and 28 days age of concrete, which is approximately 10% [15].

Thus, the combinations of those two chemical additives are studied in this paper in order to achieve an optimum proportion of a simplified model of slab bridge.

2. Methods

(1.) Aggregate Testing

Fine aggregate from Lumajang and coarse aggregate from Pasuruan are required to determine characteristics including moisture content, absorption, specific gravity, hardness, organic content, and gradation of both fine and coarse aggregates. The tests are performed based on ASTM C-29, C-33, and C-40.

(2.) Mix design

The mix design is planned by combining doses of superplasticizer (SP) and accelerator (AC), with SP of 0.8% and 1.2% by weight of cement, and AC of 2.7% and 4.5% by weight of cement. Those doses are acquired by previous trials and errors with consideration of samples that are not resulted in bleeding and segregation. The detailed results of trials and errors are summarized in **Table 1**. The suggested percentages from product instruction are 0.5% - 2% of cement weight for SP and 2% - 4.5% of cement weight for AC. The use of water with the SP admixture can be reduced by 40%. The mix design for 1 m^3 is as follows in **Table 2.**

Table 1. Superplasticizer trials

Behavoiur	SP (%)		
	0.8	1.2	2
Flow (s)	107	74	61
Slump (cm)	52	58	59

(3.) Slump-flow

The slump-flow test is used to determine the consistency of the concrete mixture and to prevent common mix design failures such as segregation and bleeding. The slump tests are conducted in the scale of laboratory. The reference for the slump-flow test is as follows in **Table 3**.

Table 2. Mix design proportion

Name	Water	Cement	Coarse Agg	Fine Agg	SP	AC
	kg	kg	kg	kg	kg	kg
Comb 1	118.4	569.4	841.9	807.7	4.56	15.38
Comb 2	118.4	569.4	841.9	807.7	4.56	25.63

Comb 3	118.4	569.4	841.9	807.7	6.83	15.38
Comb 4	118.4	569.4	841.9	807.7	6.83	25.63

Table 3. Slump-flow

Classification	***Slump-Flow* (mm)**
Slump Flow 1	550 -650
Slump Flow 2	660- 750
Slump Flow 3	760 -850

(4.) Compressive Strength

The compressive strength testings are performed based on ASTM C-495, C-873, C-116, C-39, C-215 with the actual strength is formulated in **Eq 1**. The test is conducted at the age of 0.25 days, 1 day, 7 days, and 28 days.

$$\nabla = \frac{P}{A} \quad (1)$$

∇	= compressive strength	(MPa or N/mm²)
P	= axial compressive force	(N)
A	= cross-sectional area	(mm²)

(5.) Flexural Strength

Flexural strength represents the maximum tensile strength of concrete under bending conditions. The applied loads to specimen is gradually increased until failure occurs. The flexural strength of slabs is tested using a hydraulic testing machine (Hydraulic Concrete Beam Testing Machine). The illustration of loading is depicted in **Figure 1**. The ultimate bending moment is formulated by **Eq 2** as follows:

$$M_u = \frac{P \cdot L}{4} \quad (2)$$

M_u	= ultimate bending moment	(kNm)
P	= bending force	(kN)
L	= distance between supports	(m)

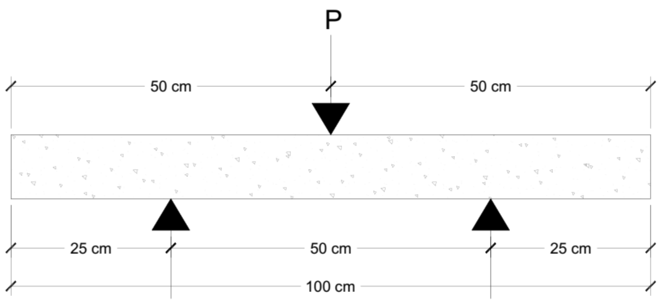

Figure 1. Flexural strength testing

The whole process of study is represented in **Figure 2** below.

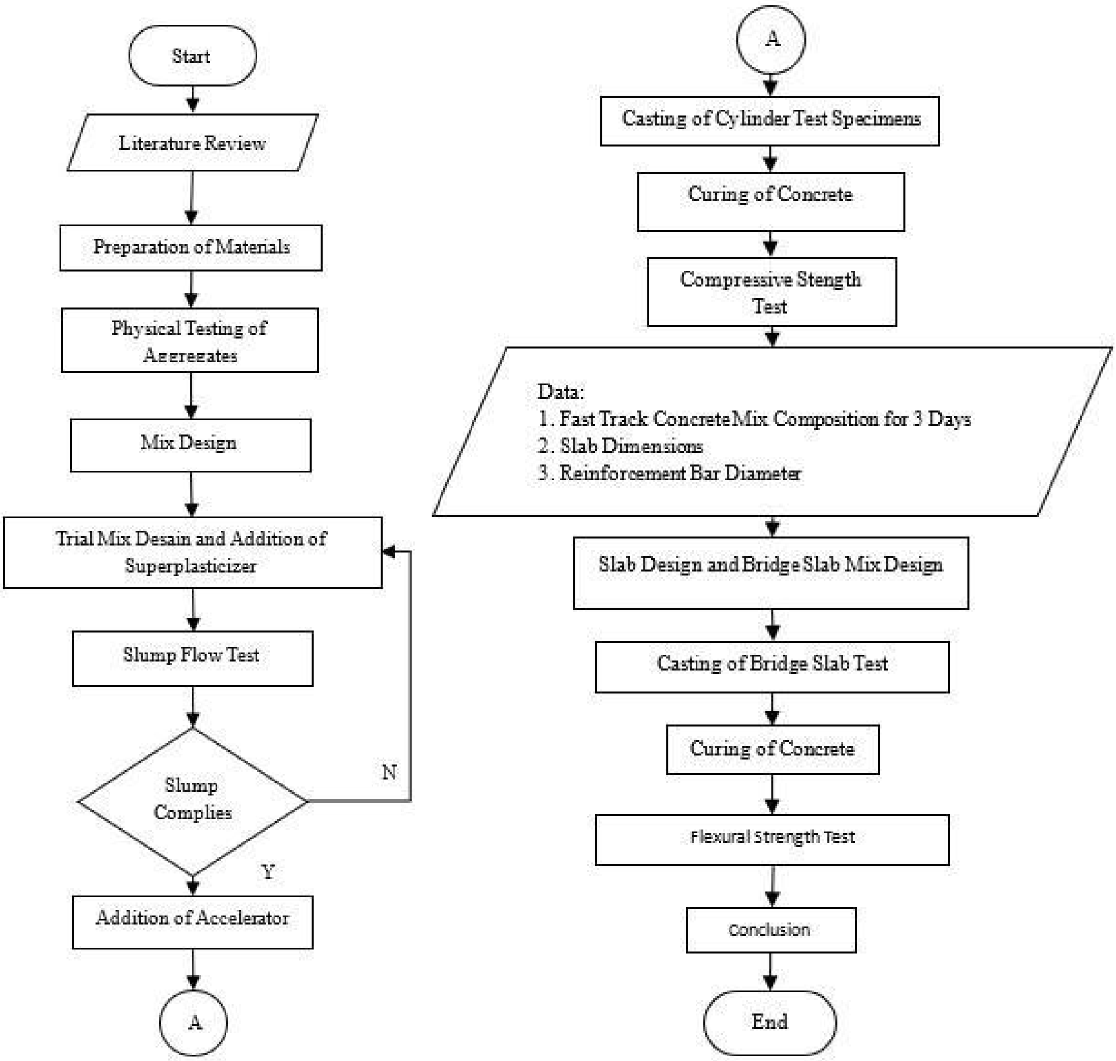

Figure 2. Flowcharts of study

3. Results and Discussions

The physical characteristics of fine and coarse aggregate are tested first to acquire the data to mix design composition. The results stated that all of the aggregates are qualified as the basic composition of the mixture. The detailed informations regarding the aggregate tests are shown in **Table 4** and **5**.

(1.) Aggregate Characteristics Testing

Table 4. Fine aggregate test results

Testing	Test Results	Reference	Standard
Gradation	Zone 1		ASTM C-33
FM	2.58	2,5 - 2,7	
BJ SSD	2.70	2,5 - 2,9	
Absorption	1.44	2% - 10%	
Water Content	3.26	5% - 10%	

Table 5. Coarse aggregate test results

Testing	Test Results	Reference	Standard
Gradation	Size 20 mm		ASTM C-29
FM	7.74	-	
BJ SSD	2.67	2,5 - 2,7	
Hardness	8.50	<45%	
Absorption	1.71	2% - 10%	
Water Content	1.66	5% - 10%	

(2.) Slump-flow Testing

Due to the use of superplasticizer and accelerator, the consistency needs to be tested by the slump-flow value because it affects workability and processing. Bleeding and segregation are suggested to be avoided, which are considered as failures in the mixing process. The slump-flow test is conducted to determine the concrete's consistency, with a target of 60 ± 10 cm. This test assesses the concrete ability to fill the mold gaps without experiencing segregation and bleeding. Detailed informations of the results are provided in **Table 6** as the measurement is illustrated in **Figure 3**.

Figure 3. Slump-flow testing

Table 6. Slump-flow test results

SP and AC dosage	Testing	Slump (cm)	Average Slump (cm)	note
SP 0.8% - AC 2.7%	slump-flow testing	60 65	62.5	meet
SP 0.8% - AC 4.5%	slump-flow testing	58 63	60.5	meet
SP 1.2% - AC 2.7%	slump-flow testing	70 62	66	bleeding
SP 1.2% - AC 4.5%	slump-flow testing	60 65	62.5	meet

(3.) Compressive Strength Testing

Compressive strength testing is performed by first weighing the concrete, followed by testing at ages of 0.25 days, 1 day, 7 days, and 28 days. The best compressive strength result at the early age of testing will be selected as the composition of modelled bridge slab.

Based on the results stated in **Figure 4**, it is fairly clear that fast-track concrete with combinations of SP and AC shows increased compressive strength correspond with age. The optimal early-age compressive strength for the mix design with a target strength of fc' 30 MPa is achieved with 1.2% SP and 4.5% AC, reaching 17.15 MPa or 57% of the planned strength for bridge deck structures, which is selected as flexural strength testing. The normal compressive strength of concrete at 7 days is 42.9 MPa, whereas concrete with the mix design of 1.2% SP and 4.5% AC reaches 56.14 MPa at 28 days. Thus, the addition of SP and AC improves the concrete quality. With interpolation, the concrete strength at 3 days reaches 100% of the planned strength, which is fc' 30 MPa.

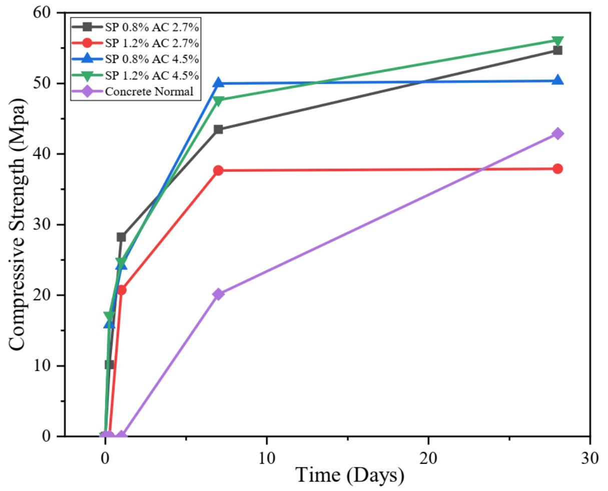

Figure 4. Compressive strength of all samples

(4.) Slab Flexural Strength Testing

Flexural strength testing was conducted on three slab samples with the same age of 3 days and dimensions of 1000 x 500 x 100 mm^3. The tests were performed using a Universal Testing Machine (UTM) with three-point bending and a span of 500 mm between supports as shown in **Figure 5**.

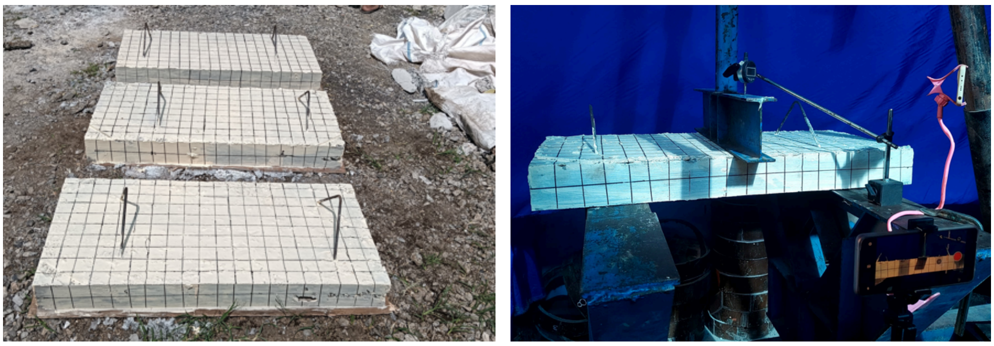

Figure 5. Flexural strength testing

The results showed the following: for specimen 1, initial cracking occurred at a load of 35 kN and failure at a load of 46 kN; for specimen 2, initial cracking occurred at 35 kN, at which point the specimen no longer resisted; and for specimen 3, initial cracking occurred at 37 kN and failure at 43 kN. The detailed data regarding those samples are shown in **Table 7**.

Table 7. Calculation results of Mu and Mn

Test Item	Ultimate Load	Ultimate Bending	Yeild Load	Yeild Bending	Nominal
	Pu (kN)	Mu (kN.m)	Py (kN)	My (kN.m)	Mn (kN.m)
I	46	5.75	35.00	4.38	3.13
II	35	4.38	35.00	4.38	3.13
III	43	5.38	37.00	4.63	3.13
Average	41.33	5.17	35.67	4.46	3.13

As results suggested, the mixture of SP and AC is applicable in real time bridge deck construction because the slab completed the hardening process only in 3 days and it is also satisfied with decent flexural strength with the load range of 35 kN to 46 kN. In the term of cost reduction, it is practically correlated with the decrease of concrete age to reach its full strength which is only 3 days. For the feasibility, the use of SP and AC are widely known by site engineer because they are easy to find in some construction additive provider.

4. Conclusions

(1.) Based on the compressive strength tests, the addition of SP and AC improves the concrete's early strength. Each treatment shows an increase in compressive strength with the aging of the concrete. For the mix design with 0.8% SP and 2.7% AC, the average compressive strength is: 10.15 MPa at 0.25 days, 28.22 MPa at 1 day, 43.46 MPa at 7 days, and 54.68 MPa at 28 days. For the mix design with 0.8% SP and 4.5% AC, the compressive strength is: 15.81 MPa at 0.25 days, 24.13 MPa at 1 day, 49.99 MPa at 7 days, and 50.34 MPa at 28 days. For the mix design with 1.2% SP and 2.7% AC, the compressive strength is: 0.00 MPa at 0.25 days due to bleeding, 20.73 MPa at 1 day, 37.67 MPa at 7 days, and 37.88 MPa at 28 days. For the mix design with 1.2% SP and 4.5% AC, the compressive strength is: 17.15 MPa at 0.25 days, 24.80 MPa at 1 day, 47.63 MPa at 7 days, and 56.14 MPa at 28 days. The mix design is planned for a concrete strength of fc' 30 MPa.

(2.) Increasing the doses of superplasticizer to 1.2% and accelerator to 4.5% by weight of cement results in increased early-age compressive strength. At 0.4 days, the compressive strength achieved is 57% of the planned strength fc'30 MPa. Therefore, the optimal mix for fast-track concrete is 569.4 kg of cement, 841.9 kg of gravel, 807.7 kg of sand, 118.4 kg of water, with 1.2% superplasticizer by weight of cement, and 4.5% accelerator by weight of cement.

(3.) Flexural strength testing was conducted at 3 days of age using concrete with fc' 30 MPa with 1.2% SP and 4.5% AC applied to a bridge deck slab with dimensions of 100 × 50 × 10 cm. The planned load for the flexural test was 33.21 kN. During testing, the average load carried by the slab was 41.33 kN. The results show that the ultimate moment is greater than the nominal moment, with a value of 5.17 kN·m compared to 3.13 kN·m, and the yield moment is also greater than the nominal moment, with a value of 4.46 kN·m compared to 3.13 kN·m. With the planned concrete quality of fc' 30 MPa and doses of 1.2% SP and 4.5% AC at 3 days, the slab structure is considered safe and adequate to support the loads acting on the bridge deck structure as per the planned design.

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