

# Substitution Of ABS Plastic Waste in Fine Aggregate on the Compressive Strength of Self-Compacting Concrete (SCC)

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## Abstract

*Self-compacting* concrete (SCC) is an innovative concrete material that can flow and compact on its own without the aid of vibrating equipment. One of the problems encountered in the development of SCC is the high demand for fine aggregate (sand), which has an impact on the exploitation of natural resources. This study aims to analyze the effect of substituting ABS plastic waste for part of the fine aggregate on the characteristics and compressive strength of SCC concrete while also contributing positively to the environment. The substitution variations used were 0, 5, 7.5, 10, 12.5, and 15 percent of the sand volume. Testing was conducted on the characteristics of fresh concrete in accordance with the EFNARC 2005 guidelines, as well as compressive strength testing at 7, 14, and 28 days of concrete age, referring to the SNI 1974:2011 method. The results showed that the addition of ABS plastic waste improved the workability of SCC concrete as the substitution rate increased due to the smooth surface of the ABS plastic waste, which reduced friction between the concrete mixtures. However, compressive strength decreased due to reduced adhesion in the concrete because the bond between the cement paste and ABS plastic was weak due to its slippery surface. Compressive strength showed that SCC concrete with ABS plastic waste substitution in fine aggregates decreased at the following substitution levels. The maximum compressive strength at 28 days had an average compressive strength of 29.64 MPa, 29.30 MPa, 28.46 MPa, 27.01 MPa, and 25.19 MPa, respectively, compared to the control concrete, which was 30.16 MPa. This indicates that 5 percent ABS plastic waste has the potential to be an environmentally friendly alternative for partial substitution of fine aggregates in SCC concrete and may be developed as a non-structural concrete mixture.

Keywords: Self-Compacting Concrete (SCC), ABS plastic waste, characteristics, fine aggregate, compressive strength.

## 1. INTRODUCTION

Concrete is one of the most frequently used construction materials compared to wood or steel. This is because concrete has high compressive strength, is easy to apply, is resistant to high temperatures, is relatively inexpensive, has readily available raw materials, and has a long service life. Therefore, the development of concrete construction material technology is of great interest. Some examples include the development of *self-compacting concrete* (SCC) by mixing other materials to reduce the use of conventional materials and simplify construction work.

As the use of gadgets, electronic devices, and vehicles has become a necessity for individuals to support their daily lives, as much as 8 million tons of ABS plastic are produced annually worldwide, but only 25% can be recycled. This has led to problems due to the excessive use of plastic in electronic devices and vehicles, which causes waste to accumulate year after year. Therefore, one innovation in partial substitution of concrete materials is the use of plastic waste as a substitute for fine aggregate in concrete *mix design*.

In a study conducted by Ullah et al. (2022), concrete compressive strength was achieved with partial substitution of fine plastic aggregate with control concrete at 30 MPa at 28 days of concrete age. The highest concrete compressive strength was achieved with a variation of electronic equipment plastic waste as a partial substitute for sand at 10%, which was 32.56 MPa at 28 days of age. In practice, plastic has not been widely used as a partial substitute for fine aggregate in concrete production, so it is necessary to analyze the effect of this substitution on concrete quality, with compressive strength as an indicator of effectiveness, so that it can be used as structural concrete. In practice, analysis of the addition of superplasticizers and ABS plastic waste as a partial substitute for sand has not been applied in the production of structural concrete mix designs. This is the background for the research on "substitution of ABS plastic waste in fine aggregates for the compressive strength of self-compacting concrete (SCC)".

## 2. RESEARCH METHOD

This research used an experimental method by comparing the planned compressive strength of  $f_c' 30$  MPa as a control with experimental concrete using ABS plastic chips as a partial substitute for fine aggregate in SCC concrete. The data observed through concrete test samples were the characteristic values and compressive strength of concrete. The conclusion drawn from the experimental results refers to the effect of using ABS plastic waste powder as a partial substitute for cement on the characteristics and compressive strength of SCC concrete.

### 2.1. Location

The research was conducted at the Structure and Material Laboratory, Faculty of Engineering and Industry Education, Indonesia University of Education, located at Jalan Dr. Setiabudhi No.207 Bandung, West Java.

### 2.2. Research sample

A total of 54 samples were used for compressive strength testing. This number was calculated based on the variation in concrete age and the percentage of ABS plastic waste substitution for fine aggregate, namely 0%; 5%; 7.5%; 10%; 12.5%; and 15% with a superplasticizer content of 1.5% of the cement weight. The test concrete was named using the following code: BSPA: ABS plastic substitution concrete.

### 2.3. Research procedure

This study was conducted by comparing the planned compressive strength of  $f_c' 30$  MPa as a control with experimental concrete using ABS plastic waste chips as a partial substitute for fine aggregate in SCC concrete. The data observed through concrete test samples was the compressive strength of the concrete. The conclusions drawn from the experimental results refer to the effect of using ABS plastic waste chips as a partial substitute for fine aggregate on the compressive strength of SCC concrete. The research was conducted with reference to work procedures referring to SNI, ASTM, EFNARC, and other sources in the form of books and previous research journal articles regarding the effect of partial substitution of ABS plastic waste in fine aggregate on concrete compressive strength.

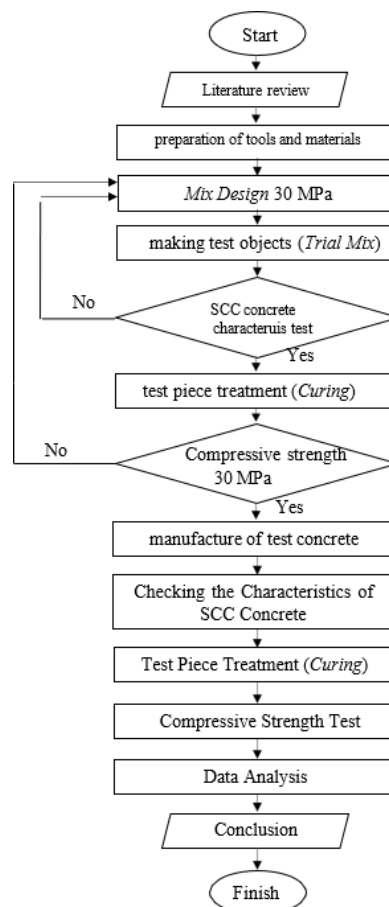


Fig 1. Research Flow Diagram

### 3. Results and Discussion

The research results consist of testing data comprising tests on the characteristics of fresh SCC concrete (flowability, viscosity, filling ability, passing ability), tests on the specific gravity of concrete, and tests on the compressive strength of concrete.

#### 3.1 SCC Concrete Characteristic Test Results

##### 3.1.1 Slump-Flow and T500 (Flowability)

The Slump-Flow and T500 tests were conducted to determine the effect of ABS plastic waste substitution in fine aggregates on the flowability of SCC fresh concrete. The tests were carried out using the EFNARC Specification and Guidelines for Self-Compacting Concrete testing standard. The results of the Slump-Flow and T500 tests are shown in Table 1.

Table 1. Flowability Test Results

Variation	Slump-Flow (mm)	Standard Slump-Flow (mm)	Slump-Flow T500 (seconds)	Standard Slump-Flow T500 (sec)
Control	590		5.53	
BSPA 5%	600		5.45	
BSPA 7.5%	650	550 - 850	5.32	3.5 - 6
BSPA 10%	660		5.25	
BSPA 12.5%	675		5.18	
BSPA 15%	690		5.05	

The results of testing the flowability characteristics of SCC concrete showed an increase in slump-flow diameter with the addition of ABS plastic waste powder substitution variations. The test results also show a decrease in the time required for fresh concrete to flow 500 mm wide as the substitution of ABS plastic powder increases. The data shows that the substitution of ABS plastic waste for fine aggregates has a significant effect on the flowability characteristics of fresh SCC concrete. The following is the implementation of the flowability test in Figure 2.



Fig 2. Slump-Flow Test Procedure

##### 3.1.2 V-Funnel (Viscosity and Filling Ability)

The V-Funnel test aims to determine the effect of ABS plastic waste substitution in fine aggregates on the viscosity of the mixture and the ability of fresh SCC concrete to fill the mold. The test was conducted using the EFNARC Specification and Guidelines for Self-Compacting Concrete test standard. The results of the V-Funnel test can be seen in Table 2.

Table 2. *Viscosity and Filling Ability* Test Results

Variation	V-Funnel (sec)	Standard V-Funnels (sec)
Control	10.9	5 - 25
BSPA 5%	8.69	
BSPA 7.5%	7.38	
BSPA 10%	6.69	
BSPA 12.5%	6.08	
BSPA 15%	5.99	

The SCC concrete characteristic test results, namely passing ability, show an increase in the ratio of H2 and H1 heights of fresh concrete in the l-box device. The height H2 of fresh concrete increased with the addition of ABS plastic powder substitution variations. Meanwhile, the height H1 decreased with the addition of ABS plastic substitution variations. The data shows that the substitution of ABS plastic powder for fine aggregates has a significant effect on the passing ability characteristics of fresh SCC concrete. The following are the passing ability test results in Figures 4.4 and 4.5.



Fig 3. Implementation of the V-Funnel Test

### 3.1.3. L-Box (Passing Ability)

The L-Box test aims to determine the effect of ABS plastic waste substitution in fine aggregate on the ability of fresh SCC concrete to pass through the reinforcement gaps in concrete. The test was conducted using the EFNARC Specification and Guidelines for Self-Compacting Concrete. The results of the L-Box test can be seen in Table 3.

Table 3 *Passing Ability* Test Results

Variation	L-Box (H2/H1)			L-Box Standard (H2/H1)
	H1 (mm)	H2 (mm)	(H2/H1)	
Control	94	79	0.84	≥ 0.8
BSPA 5%	94	80	0.85	
BSPA 7.5%	93	81	0.87	
BSPA 10%	92	81	0.88	
BSPA 12.5%	90	82	0.91	
BSPA 15%	9	9	1	

The SCC concrete characteristic test results, namely passing ability, show an increase in the ratio of H2 and H1 heights of fresh concrete in the l-box device. The height H2 of fresh concrete increased with the addition of ABS plastic powder substitution variations. Meanwhile, the height H1 decreased with the addition of ABS plastic substitution variations. The data shows that the substitution of ABS plastic powder for fine aggregates has a significant effect on the passing ability characteristics of fresh SCC concrete. The following is the implementation of the passing ability test in Figure 4.



Fig. 4. Implementation of the H1 L-Box Test

### 3.2 Results of Concrete Specific Gravity Testing

The concrete density test aims to determine the effect of ABS plastic waste powder substitution in fine aggregate on concrete density. The test was carried out by dividing the weight by the volume of the test specimen. The results of the concrete density test can be seen in Table 4.

Table 4. Specific Gravity Test Results

Variation	Specific Gr			Average Specific Gravity
	7 Days	14 Days	28 Days	
Control	2259.58	2280.37	2287.80	2275.92
BSPA 5%	2264.67	2271.46	2236.87	2257.67
BSPA 7.5%	2272.52	2246.42	2251.94	2256.96
BSPA 10%	2281.01	2196.55	2253.85	2243.80
BSPA 12.5	2226.68	2219.68	2229.02	2225.13
BSPA 15%	2213.74	2186.79	2216.71	2205.75

The test results show a decrease in average specific gravity with the addition of ABS plastic waste substitution in fine aggregate. The data shows that the substitution of ABS plastic waste for fine aggregate has an effect on changes in concrete specific gravity because the specific gravity is smaller than that of fine aggregate, causing a decrease in specific gravity.

### 3.3 Concrete compressive strength test results

Concrete compressive strength testing aims to determine the effect of ABS plastic waste substitution in fine aggregate on the capacity of concrete to withstand loads. The test was carried out using a compression test device with a maximum load capacity of 1500 kN and the SNI-1974-2011 test standard. The compressive strength test was carried out with concrete ages of 7, 14, and 28 days. The test results can be seen in Tables 5, 6, and 7.

Table 5. Compressive Strength Test Results at 7 Days

Variation	Sample Weight	Cross-sectional Area (mm)	Load (kN)	7-day Compressive Strength (MPa)	Average
Control	3,552	7,853.982	159.8	20,346	19,935
	3,495	7,853.982	153.1	19,493	
	3,601	7,853.982	156.8	19,964	
BSPA 5%	3,566	7,853.982	159.8	20,346	19,969
	3,610	7,853.982	154.7	19,697	
	3,496	7,853.982	156	19,863	
BSPA 7.5%	3,545	7,853.982	148.5	18,908	18,844
	3,527	7,853.982	138.7	17,660	
	3,637	7,853.982	156.8	19,964	
BSPA 10%	3,493	7,853.982	153.7	19,570	18,046
	3,830	7,853.982	132.8	16,909	
	3,426	7,853.982	138.7	17,660	
BSPA 12.5%	3,536	7,853.982	136.6	17,392	16,306
	3,423	7,853.982	118.9	15,139	
	3,534	7,853.982	128.7	16,387	
BSPA 15%	3,479	7,853.982	128.7	16,387	16,170
	3,487	7,853.982	125.3	15,954	
	3,466	7,853.982	127	16,170	

Table 6. Results of 14-Day Compressive Strength Test

Variation	Sample Weight	Cross-sectional Area (mm)	Load (kN)	14-Day Compressive Strength (MPa)	Average
Control	3,676	7,853.982	196.9	25,070	26,101
	3,592	7,853.982	204.0	25,974	
BSPA 5%	3,478	7,853.982	214.1	27,260	25,919
	3,576	7,853.982	202.2	25,745	
	3,479	7,853.982	195.7	24,917	
BSPA 7.5%	3,649	7,853.982	212.8	27,095	25,439
	3,63	7,853.982	196.9	25,070	
	3,489	7,853.982	194.0	24,701	
BSPA 10%	3,467	7,853.982	208.5	26,547	24,590
	3,435	7,853.982	201.3	25,630	
	3,478	7,853.982	187.1	23,822	
BSPA 12.5%	3,438	7,853.982	191.0	24,319	23,496
	3,5	7,853.982	182.2	23,198	
	3,491	7,853.982	186.9	23,797	
BSPA 15%	3,469	7,853.982	184.5	23,491	22,978
	3,424	7,853.982	189.6	24,141	
	3,395	7,853.982	169.1	21,530	
	3,486	7,853.982	182.7	23,262	

Table 7. Results of 28-Day Compressive Strength Test

Variation	Sample Weight	Cross-sectional Area (mm)	Load (kN)	28-Day Compressive Strength (MPa)	Average
Control	3,554	7,853.982	228.9	29,144	30,163
	3,587	7,853.982	236.9	30,163	
	3,64	7,853.982	244.9	31,182	
BSPA 5%	3,557	7,853.982	240.6	30,634	29,641
	3,503	7,853.982	234.9	29,908	
	3,481	7,853.982	222.9	28,381	
BSPA 7.5%	3,5	7,853.982	228.7	29,119	29,297
	3,501	7,853.982	227.3	28,941	
	3,611	7,853.982	234.3	29,832	
BSPA 10%	3,617	7,853.982	234.9	29,908	28,461
	3,457	7,853.982	222.9	28,381	
	3,547	7,853.982	212.8	27,095	
BSPA 12.5%	3,591	7,853.982	207.0	26,356	27,010
	3,483	7,853.982	216.6	27,578	
	3,43	7,853.982	212.8	27,095	
BSPA 15%	3,543	7,853.982	183.4	23,351	25,189
	3,493	7,853.982	207.9	26,471	
	3,41	7,853.982	202.2	25,745	

The results of the concrete compressive strength test show an increase in concrete compressive strength for each variation as the concrete ages. The lowest compressive strength occurred in concrete aged 7 days with a 15% substitution variation. Meanwhile, the highest compressive strength occurred in concrete aged 28 days with a 0% substitution variation.

### 3.4 Discussion of SCC Concrete Characteristic Test Results

#### 3.4.1. Slump-Flow and T500 (Flowability)

The results of the slump-flow and T500 tests on fresh SCC concrete for each variation of ABS plastic waste substitution are shown in consecutive graphs in Figures 5 and 6.

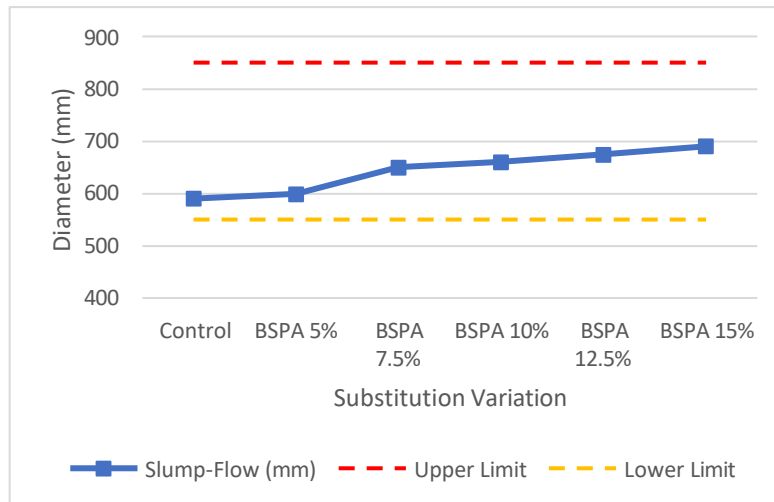


Fig 5. *Slump-Flow* Diameter

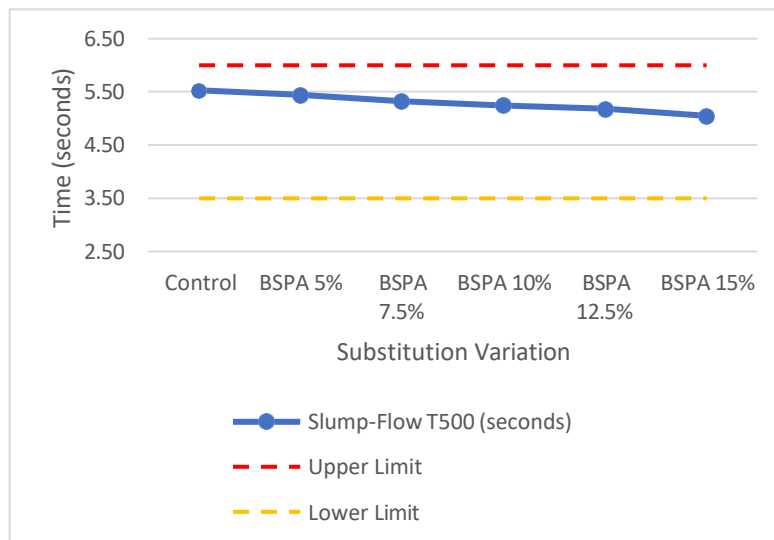


Fig. 6. *Slump-Flow* Time T500

The *slump-flow* test results show that fresh SCC concrete with 5% partial substitution of ABS plastic waste in fine aggregate has the lowest *slump-flow* diameter of 600 mm. Meanwhile, fresh SCC concrete with the highest *slump-flow* diameter occurs in the 15% substitution variation of fine aggregate, which is 690 mm.

The *flowability* characteristics of fresh SCC concrete were also tested using the T500 *slump-flow* test, which showed a decrease in the time required for fresh concrete to reach a diameter of 500 mm. The lowest T500 value occurred in concrete with a 15% substitution variation ( ) or the control concrete, which was 5.05 seconds. Meanwhile, the highest T500 value occurred in concrete with a 0% substitution variation, which was 5.53 seconds.

### 3.4.2. V-Funnel (Viscosity and Filling Ability)

The results of the *V-funnel* test on fresh SCC concrete for each variation of ABS plastic waste powder substitution are displayed in graphical format in Figure 7.

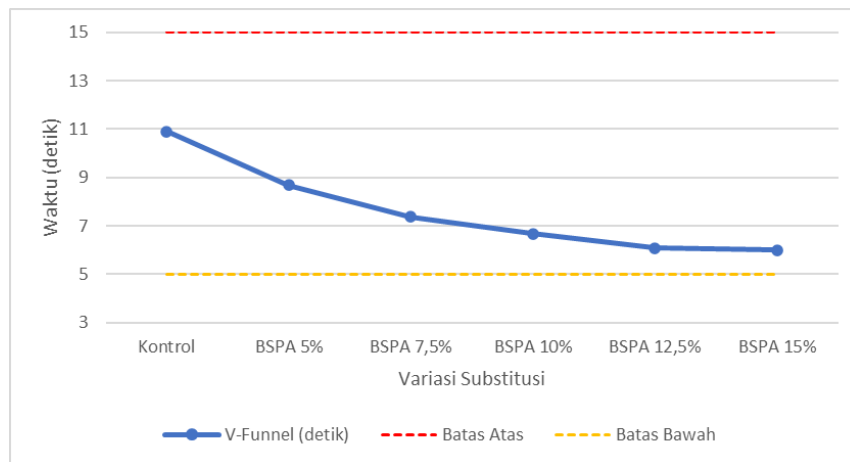


Fig 7. *V-Funnel* Time

The *v-funnel* test results show that fresh SCC concrete with 0% ABS plastic waste powder substitution in fine aggregate has the highest flow time of 10.9 seconds. Meanwhile, fresh SCC concrete with the lowest flow time occurs in the 15% substitution variation in fine aggregate, which is 5.99 seconds. These results indicate a 45% decrease in concrete flow time in fresh SCC concrete with 15% ABS plastic waste powder substitution compared to control SCC concrete.

### 3.4.3. V-Funnel (Viscosity and Filling Ability)

The results of the *L-box* test on fresh SCC concrete for each variation of ABS plastic waste powder substitution are displayed in graphical format in Figure 8.

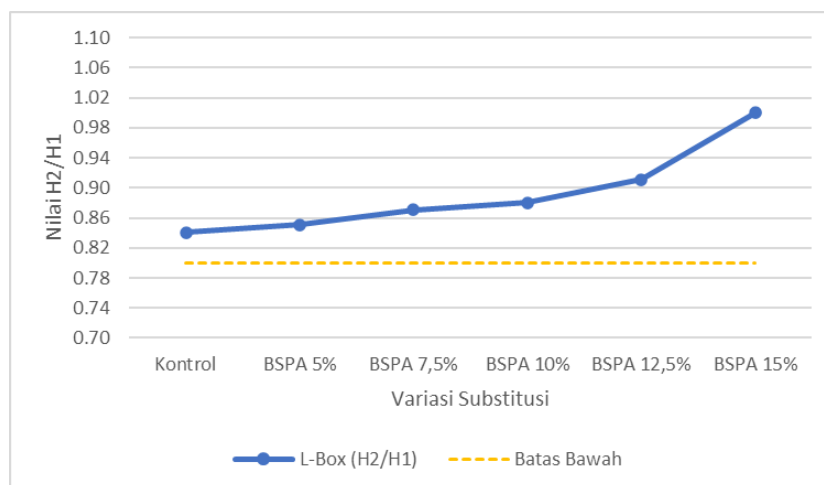


Fig. 8. H2/H1 *L-Box* Values

The *L-box* test results show that fresh SCC concrete with 0% ABS plastic waste powder substitution in fine aggregate has the lowest H2/H1 value, namely 0.84. Meanwhile, fresh SCC concrete with the highest H2/H1 value occurred in the 15% substitution variation for fine aggregate, which was 1. These results show a 19% increase in the H2/H1 value in fresh SCC concrete with 15% ABS plastic waste powder substitution compared to the control SCC concrete.

### 3.4.3. V-Funnel (Viscosity and Filling Ability)

The results of *l-box* testing on fresh SCC concrete for each variation of ABS plastic waste powder substitution are shown in graph format in Figure 12.

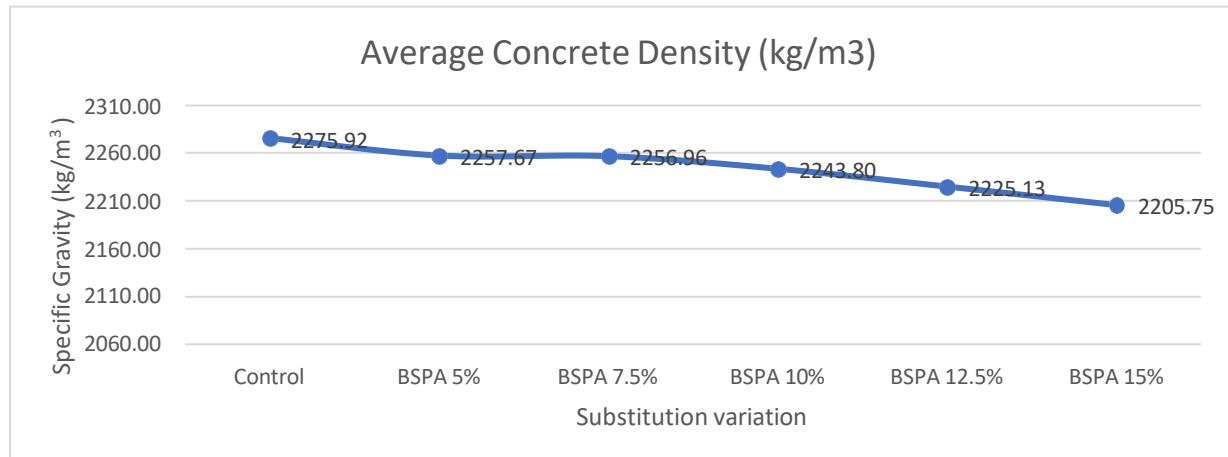


Fig. 9. Average Specific Gravity of Concrete

The test results in Figure 4.5 show a decrease in the average specific gravity of concrete at 7, 14, and 28 days with increasing variations in the substitution of ABS plastic waste powder for fine aggregate. This is because ABS plastic waste powder has a lower specific gravity of 1006 kg/m<sup>3</sup> compared to sand, which is 2469 kg/m<sup>3</sup>. The greater the volume of fine aggregate substituted by ABS plastic waste powder, the greater the reduction in the total weight of the concrete mixture. This affects the density of hard concrete, which will decrease overall as the substitution of ABS plastic waste for fine aggregate increases.

### 3.5 Discussion of Concrete Compressive Strength Test Results

3.5.1. Compressive Strength of Concrete at 7, 14, and 28 Days The results of the *l-box* test on fresh SCC concrete for each variation of ABS plastic waste powder substitution are presented in graphical format in Figure 10.

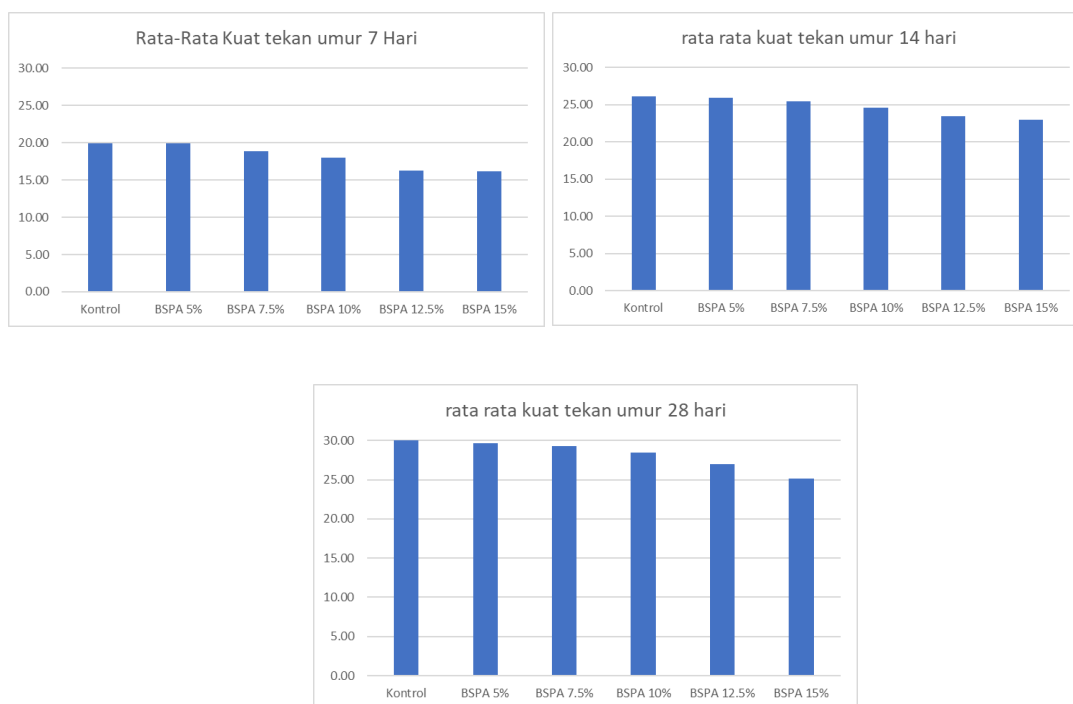


Fig. 10. Average Compressive Strength at 7, 14, and 28 Days

Compressive strength was tested using a compression test machine with concrete ages of 7, 14, and 28 days. The results show that the compressive strength of the concrete varied, increasing and decreasing with each variation until reaching a maximum increase at a 5% substitution. The concrete then experienced a decrease in compressive strength at substitution variations of 7.5% to 15%.

3.5.2. The results of the compressive strength test on fresh SCC concrete aged 7 days, 14 days, and 28 days for each variation in ABS plastic waste powder substitution are compared in a graph and bar chart, respectively, in Figure 11.

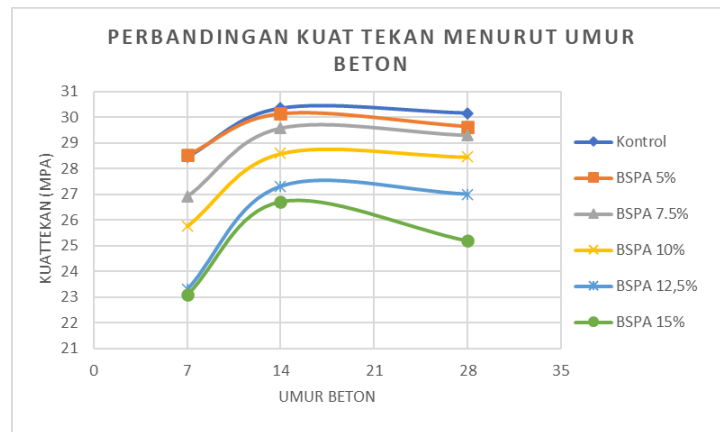


Fig. 11. Comparison of Compressive Strength According to Concrete Age

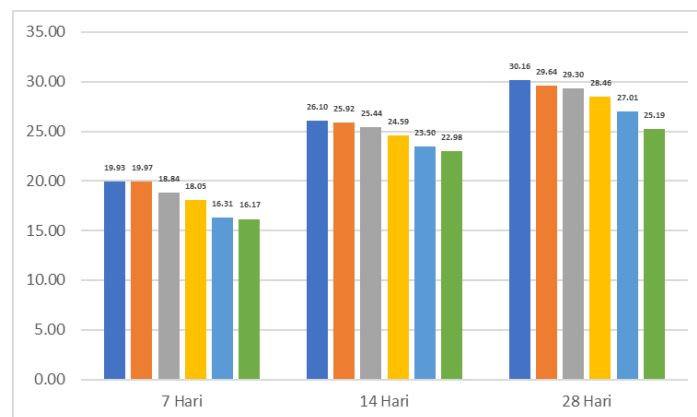


Fig. 12. Compressive Strength According to Substitution Variation and Concrete Age

Figures 11 and 12 show a comparison of the compressive strength of concrete with different ages. The results of the study indicate that the compressive strength of SCC concrete with ABS plastic waste powder substitution in each variation decreases with increasing concrete age. The highest compressive strength in each substitution variation occurred at 28 days of concrete age.

The results showed that SCC concrete substituted with ABS plastic waste in fine aggregates exhibited increased workability and decreased concrete compressive strength in each substitution variation. The highest compressive strength occurred in the 5% substitution variation at 28 days. The decrease in mechanical properties occurred in the compressive strength of concrete with ABS plastic waste substitution. This is closely related to adhesion, due to the attractive force between the cement paste molecules and the aggregate surface. Natural sand has high adhesion due to its rough texture, allowing the cement paste to "lock" mechanically. However, ABS plastic waste has a smooth texture, which drastically reduces adhesion strength. The cement paste cannot adhere strongly, resulting in a weak bond between the cement paste and the aggregate, which causes a decrease in concrete compressive strength. The increase in workability is caused by the smooth surface of ABS plastic aggregate, which reduces friction between particles. This results in concrete mix with higher slump

compared to normal concrete with the same water-cement ratio. The results of this study are in line with previous studies, namely the substitution of plastic fine aggregates in concrete for sustainable production. Workability increases with increasing substitution because the plastic is slippery, making the mixture easy to flow, and the smoother shape and texture of the plastic can reduce friction between particles. Compressive strength decreased from the control concrete value because the role of cement as a binder or adhesive in concrete was reduced, causing the chemical and mechanical bonding of the mixture to become unbalanced.

The results of the study show that the maximum compressive strength occurs in the 5% substitution variant, so that the sand requirement of 943 kg/1 m<sup>3</sup> in concrete can be replaced with 32.2 kg/1 m<sup>3</sup> of ABS plastic waste, thereby reducing the need for sand in the field and utilizing ABS plastic waste, which increases every year. Thus, this research will be highly beneficial for further development, considering the trend toward sustainable development, particularly regarding sand requirements in the construction industry, waste utilization, and reducing the negative environmental impact of the concrete industry.

#### 4. Conclusions

Based on the results and discussion of the research, the following conclusions were drawn:

1. The characteristics of SCC concrete with ABS plastic waste substitution show an increase in workability, marked by an increase in slump flow value as the substitution content increases, because plastic has a smooth surface, thereby reducing friction between mixtures.
2. Substitution of ABS plastic waste in fine aggregates reduces the compressive strength of SCC concrete at 28 days of age, due to reduced adhesion between the cement paste and plastic aggregates, which have a slippery surface. SCC concrete with ABS plastic waste substitution in fine aggregates at 28 days of age has an average compressive strength at substitution variations of 0%, 5%, 7.5%, 10%, 12.5%, and 15% substitution, respectively, of 30.16 MPa, 29.64 MPa, 29.30 MPa, 28.46 MPa, 27.01 MPa, and 25.19 MPa.
3. The maximum compressive strength occurred in 28-day-old SCC concrete with a 5% ABS plastic waste substitution variation, with a compressive strength of 29.64 MPa.

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