# EFFECT OF SILICA FUME SUBSITITUTION IN CEMENT AND ADDITION OF POLYPROPYLENE FIBER

**Resti Nur Arini[1], Farhan Rizky Yulihendrika[1], Fadli Kurnia[1], Ramadhani Isna[2]**
[1] Program Studi Teknik Sipil, Fakultas Teknik, Universitas Pancasila
[2] Program Studi Arsitektur, Fakultas Teknik, Universitas Pancasila
E-mail: resti.nurarini@univpancasila.ac.id

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***ABSTRACT***

*To fulfill the needs of construction materials both structural and non-structural in concrete, concrete forming materials are needed that have good resistance to the environment and can also improve the mechanical properties of concrete. One of the materials that can help improve the mechanical properties of concrete is by adding polypropylene fiber and silica fume to the mixture. The addition of silica fume as a substitute for cement is one of the alternatives used to utilize waste so as to reduce the use of cement. besides adding silica fume, the addition of polypropylene fiber can also affect physical properties because one of the advantages of using polypropylene fiber can reduce cracking at a young age. So by adding polypropylene fiber and silica fume into the mixture is expected to increase the compressive strength. In this research, we will substitute silica fume for cement and add polypropylene fibers to the concrete mix. The percentage of silica fume used for cement substitution is 2%, 4%, 6% and 8% while for fiber addition is 1% and 0.5%. From the results of silica fume substitution and the addition of polypropylene fiber, the maximum compressive strength value of the mortar will be sought. From the results of the compressive strength test, the addition of 0.5% polypropylene fiber and the addition of 8% silica fume produced the highest compressive strength, which is around 6.02 MPA.*

***Keywords:*** *Mortar, Silica fume, Polypropylene Fibers, Compressive Strength*

## INTRODUCTION

The development of construction materials for structural or non-structural needs in concrete mixtures must have good resistance to the environment, so that in making concrete mixtures must have content that can bind particles and be able to increase strength in concrete. The manufacture of high quality concrete or mortar with substitute materials is gradually developing so that it can replace normal quality concrete, especially concrete that is directly related to heavy loads and has aggressive environmental conditions that cause concrete to become very brittle. The addition of substitutes to the concrete mix is micronized to ensure that the concrete can produce high strength and low permeability. (Aydin, Yazici, & Baradan, 2008).

Concrete is a very brittle material that requires strength to increase the strength of the concrete, this is due to the low tensile strength and lack of bond in the cement. So to increase ductility in concrete, the addition of fiber and other substitution mixtures is needed as a solution to improve the quality of concrete. The addition aims to increase the energy absorption of concrete to become more ductile. (Nili & Afroughsabet, 2010). One of the alternative materials in concrete mixtures as a substitute for cement and other additives to improve the quality of concrete by utilizing the use of industrial waste such as silica fume. Silica fume is a silicon and ferro-silicon metal waste that can be used as a renewable material. Silica fume is often used to replace cement in order to reduce cement content and save costs, besides that silica fume can also function as an additive that can improve the physical properties of concrete. (Zhang & Li, 2013) (Siddique, 2011).

Utilization of silica fume has the advantage that it can increase durability and strength in concrete. Research conducted by Goran.etl. the use of silica fume as much as 5% also shows that silica fume can increase workability, strength and durability in concrete. (Adil, Kevern, & Mann, 2020). In addition, in a study conducted by Bantot, et al, the use of silica fume showed a minimum absorption value of 3.276% obtained from a mixture with 15% silica fume and the use of an 8% silica fume mixture produced a maximum compressive strength of 312.574.kg/cm$^2$ (Sutriono, Trimurtiningrum, & Rizkiardi, 2018). The use of silica fume in concrete in addition to improving the mechanical properties of concrete, fine silica fume can provide a strong bond to the cement paste so that it can affect the performance of fresh concrete this is due to the intermolecular changes contained in silica fume in the form of calcium hydrate to calcium silicate hydrate to be reactive, but the more silica fume is added to fresh concrete it will reduce the compressive strength of concrete (Bing, Jie, & Long-zhu, 2009) (Garg & Garg, 2020). The addition of silica fume can increase the compressive strength of concrete by 30% at the age of 91 days, this shows that there is a pozzolanic effect that affects the fresh concrete content, so that the addition of silica fume to the mixture by itself increases the compressive strength (Nili & Afroughsabet, 2010). In addition, the use of silica fume as a partial substitution of cement in concrete has advantages including reduced CO2 emissions, cost-effective concrete, increased durability, and can improve mechanical properties. By utilizing the optimum substitution between cement and silica fume, it can be utilized as one of the sustainable construction materials. (Nafees, et al., 2021).

To prevent cracking in young concrete, fiber addition can be done to prevent crack propagation. One fiber that can be used in concrete mixtures is polypropylene fiber. Polypropylene fiber is a synthetic fiber that has a low modulus of elasticity, high strength, increases ductility and improves durability. (Li, Zhang, & Sun, 2011). For concrete mixtures, the addition of polypropylene fibers in cement mixtures can increase tensile strength, besides the use of excess fibers will cause several factors that can affect the performance of the mixture such as fiber length, distribution interval and volume fraction. The use of polypropylene fibers can suppress cracks in concrete and can produce high compressive strengths (Xue, Yilmaz, Song, & Cao, 2020) (Fallah & Nematzadeh, 2016).

The use of polypropylene fibers can affect the physical, mechanical and thermal properties of concrete because in reinforced concrete, polypropylene fibers will melt at a temperature of 160o-170oC and evaporate around 340oC, it will form voids in concrete if the fibers have changed shape. (Tanyildizi, 2009) Adding polypropylene fibers that are too short will have an influence on compressive strength and split tensile strength. While the addition of polypropylene fibers that are too long can increase durability and stability, especially when shrinkage decreases significantly. The utilization of the amount of fiber in 1m3 of concrete can be seen in Table 1 (Latifi, Biricik, Aghabaglou, & Mardani, 2021)

**Table 1**. Utilization of fiber count per 1m$^3$ in concrete production (Latifi, Biricik, Aghabaglou, & Mardani, 2021)

| Polypropylene | Interior | Exterior | Heavy-duty |
|---|---|---|---|
| Fiber type | M | F | F |
| Minimum dosis (g/m3) | 600 | 900 | 1800 |
| Optimum dosis (g/m3 | 1200 | 2700 | 3600 |
| Length (mm) | 6-9-12-15 | 6-9-12-15-19-25 | |

The use of a mixture of silica fume and polypropylene fibers in the mixture provides advantages in tensile and flexural strength compression due to the effect of using fibers, this is considered as strengthening and stiffening the cement paste which increases the bond between particles, in addition, mixtures using silica fume and fibers can increase the split tensile strength by about 25-38% at 28 days and 46-57% at 180 days (Ali, Raza, Hussain, & Iqbal, 2020). The addition of polypropylene fiber can adversely affect the workability of the mixture, this is because the volume of fiber inhibits the stirring process so that it will gradually decrease, but adding silica fume can increase the durability of concrete so that concrete using polypropylene fiber and silica fume can reduce water permeability, cracks become controlled, and increase compressive strength and reduce shrinkage so that the crack control ability is very effective. (Zhang & Li, 2013) (Medina, Barluenga, & Olivares, 2015).

In this study, we will mix silica fume as a substitute for cement and polypropylene fiber as an additive with the aim of knowing the highest compressive strength value of the mortar mixture. So that from the test results obtained, it is hoped that the maximum mixture used can be used in non-structural materials such as lightweight bricks and roof tiles.

## METHOD

### Flow chart

In conducting research testing, the stages are carried out in analyzing the manufacture of test objects. The test steps can be seen in the flow chart on **Figure 1**.

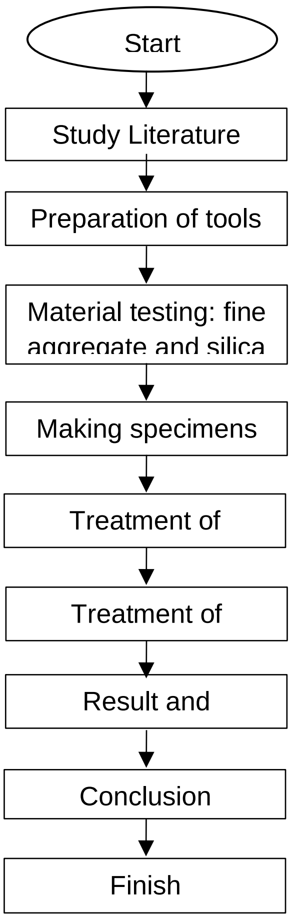


**Figure 1.** Research Flow chart

In this study will make mortar with a mold size of 5x5x5 cm, the purpose of using a mortar mold is to find the maximum percentage value between the composition of silica fume and polypropylene fiber that has the highest compressive strength. Testing the compressive strength of mortar refers to SNI 03-6825-2002. The percentage used for the composition of silica fume substitution to cement is 2%, 4%, 6% and 8%. While for polypropylene fiber as much as 0.5% and 1%.

**Figure 2**. Making of test specimens

### Material Testing

Material testing is carried out referring to SNI 1970: 2008 to determine the content of the material, namely fine aggregate to be used in research. The results of the tests carried out can be seen in **Table 2**.

**Table 2.** Fine Aggregate Testing

| Properties | unit | Fine aggrregate | Limit |
|---|---|---|---|
| Specific gravity | Kg/L | 2,605 | 2,5-2,6 |
| Absorption | % | 1,88 | 1,87-1,88 |
| weight of contents | Kg/L | 1,55 | |
| Silt content | % | 3 | 5% |
| Organic content | - | Tua | Tua |
| FM | - | 2,67 | |

### Mix Design

The materials used in the concrete mix used type 1 cement, silica fume from Masterlife SF 100 and polypropylene fiber from Kratos Micro 12mm/microfiber/PPF PolyproPylene Fiber. The mix design for mortar can be seen in **Table 3**.

**Table3**. Mix Design

| Code | Composition | | | |
|---|---|---|---|---|
| | Cement | Silica fume | Polypropylene fiber | Sand |
| SP2% | 388 | 8 | 4 | 1200 |
| SP4% | 380 | 16 | 4 | 1200 |
| SP6% | 372 | 24 | 4 | 1200 |
| SP8% | 364 | 32 | 4 | 1200 |
| PS2% | 390 | 8 | 2 | 1200 |
| PS4% | 382 | 16 | 2 | 1200 |
| PS6% | 374 | 24 | 2 | 1200 |
| PS8% | 366 | 32 | 2 | 1200 |

In the naming code, the test objects are divided into 2 types, namely for the addition of 1% polypropylene fiber will be given the SP code while for the addition of 0.5% fiber will be given the PS code. Each test specimen is made as many as 6 pieces for 2 different treatment methods. So that a total of 144 test specimens will be made.

**Test specimen Treatment Method**

In this research, 2 methods will be carried out, namely room temperature and soaking in water. The test specimens will be treated at the age of 7, 14 and 28 days before testing. The purpose of doing the difference between the two methods is to determine the compressive strength characteristics of the test specimen.

**Figure 3**. Soak Treatment


**Figure 4**. Room Temperature Treatment

**Setting time test**

The setting time test was carried out to determine the ability of the setting time between cement substituted with silica fume. By doing this test, it can determine the speed of the binding time of the subsumed paste.

**Figure 5.** Setting time test

**Compressive Strength Test**

The mortar compressive strength test is carried out when the mortar has reached the testing age. The test formula for calculating the compressive strength results can be calculated by equation 1:

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

where:

F = compressive strength (MPa)
P = Maksimum Load (N)
A = Surface area of the test specimen ($mm^2$)

**RESULT AND DISCUSSION**

**Setting time test.**

The setting time test for cement paste subsituted with silica fume can be seen in **Figure 6**.

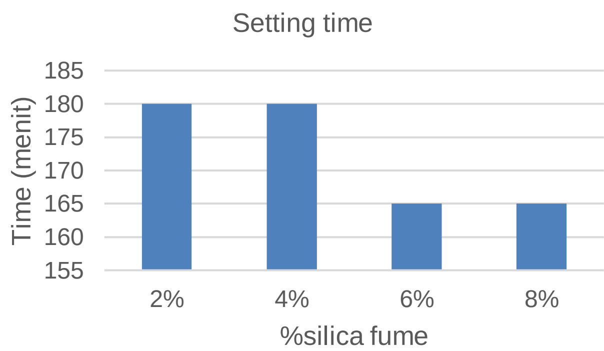


**Figure 6**. Setting time between cement and silica fume

**Figure 6** shows that the percentage of cement substitution shows that the paste setting time becomes faster. This shows that the pozzolan content contained in silica fume can affect the setting time between particles. From the test results, the fastest binding time is in SP3 and SP4 at 165 minutes.

**Mortar Compressive Strength Testing**

The compressive strength test was conducted at the age of 7, 14 and 28 days. In **Table 4** are the results of the average compressive strength with a percentage of polypropylene fiber of 1%, while for **Figure 7** and Figure 8 is the trend of increasing compressive strength of the test results at each age.

**Table 4.** Comparative compressive strength for 1% polypropylene fiber percentage

| %polypropylene fiber | SP | | | |
|---|---|---|---|---|
| silica fume | 2% | 4% | 6% | 8% |
| | Compressive strength (MPa) room temperature treatment | | | |
| 7 | 2,35 | 2,51 | 2,2 | 2,93 |
| 14 | 2,88 | 3,77 | 3,56 | 4,34 |
| 28 | 4,81 | 4,92 | 4,87 | 4,76 |
| | Compressive strength (MPa) soak treatment | | | |
| 7 | 3,56 | 3,24 | 2,86 | 3,24 |

| | | | | |
|---|---|---|---|---|
| 14 | 3,71 | 4,08 | 4,08 | 4,37 |
| 28 | 5,23 | 5,28 | 5,23 | 5,18 |

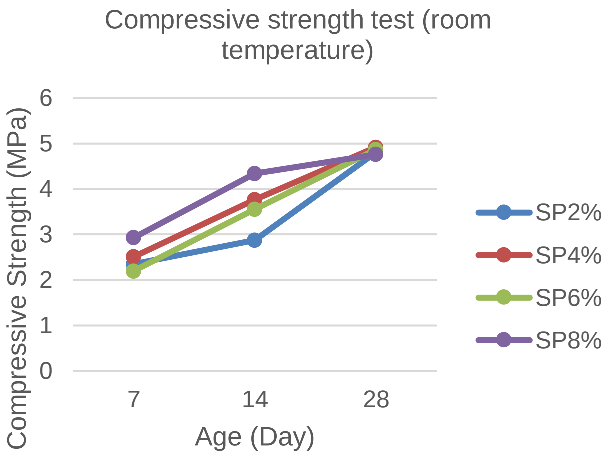


**Figure 7**. Compressive strength of mortar 1% polypropylene fiber room temperature treatment

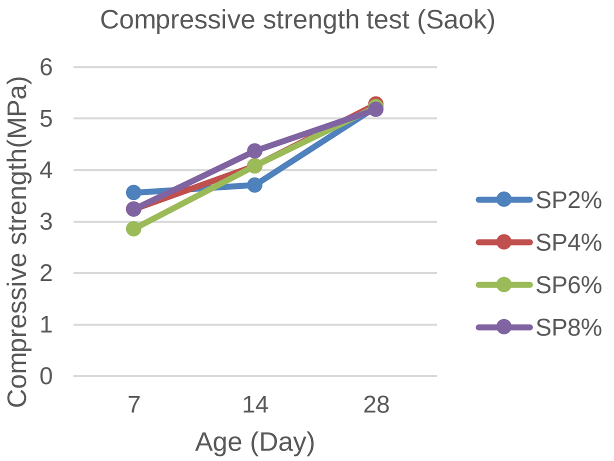


**Figure 8**. Compressive strength of mortar 1% polypropylene fiber soaked treatment

**Table 4** shows the results of the highest compressive strength test seen in the silica fume content of 4% at the age of 28 days obtained the results of compressive strength, namely in water treatment of 5.28 MPa and for room temperature treatment has a result of 4.92 MPa. From the results of the compressive strength test with a mixture of polypropylene fiber as much as 1% against both treatment methods with the addition of a percentage of silica fume into the mixture shows a decrease in compressive strength. This is because the addition of polypropylene fiber silica fume has an impact on the strength of the mortar.

In **Table 5** are the results of the average compressive strength with a percentage of polypropylene fiber as much as 0.5%, while for, **Figure 9** and **Figure 10** are the upward trend of the compressive strength of the test results at each age.

**Table 5**. Comparative results of compressive strength for 0.5% polypropylene fiber percentage.

| %polypropylene fiber | PS | | | |
|---|---|---|---|---|
| silica fume | 2% | 4% | 6% | 8% |
| | Compressive strength (MPa) room temperature treatment | | | |
| 7 | 3,14 | 3,19 | 3,66 | 3,87 |
| 14 | 3,87 | 4,08 | 4,34 | 4,39 |
| 28 | 5,13 | 5,23 | 5,18 | 5,81 |
| | Compressive strength (MPa) soak treatment | | | |
| 7 | 3,4 | 3,45 | 3,87 | 3,98 |
| 14 | 4,08 | 4,24 | 4,45 | 4,45 |
| 28 | 5,49 | 5,81 | 5,76 | 6,02 |

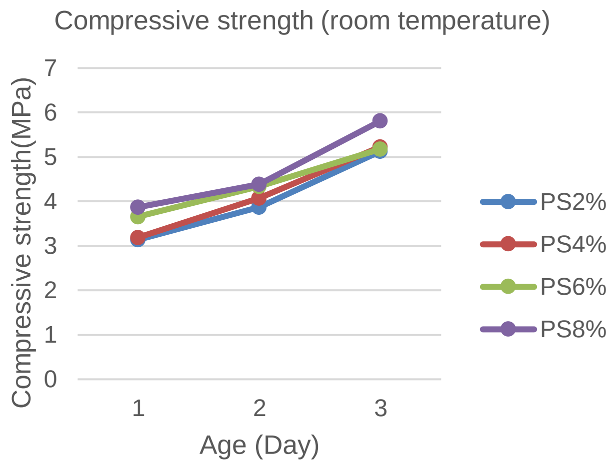


**Figure 9**. Compressive strength of mortar 0.5% polypropylene fiber room temperature treatment

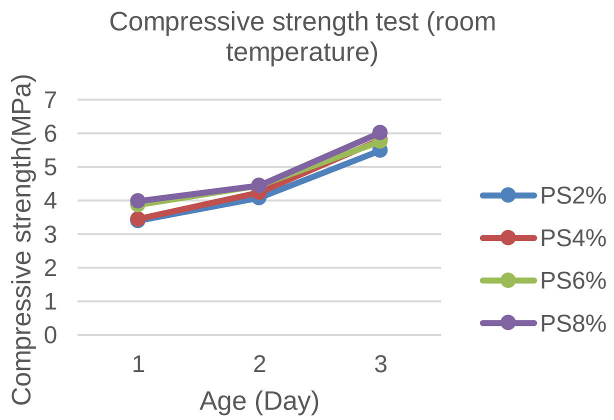


**Figure 10**. Compressive strength of mortar 0.5% polypropylene fiber soaked treatment

**Table 5** shows the results of the highest compressive strength test seen in the silica fume content of 8% at the age of 28 days has the highest compressive strength results, namely in water treatment of 6.02 MPa and for room temperature treatment has a result of 5.81 MPa. From the test results of compressive strength with a mixture of polypropylene fibers as much as 0.5% of both treatment methods with the addition of silica fume percentage into the mixture shows an increase in compressive strength.

**Comparison of compressive strength of 28-day mortar ages**

From the results of the average compressive strength test, the highest compressive strength at the age of 28 days was compared to the percentage of polypropylene fiber 1% and 0.5%. the comparison results can be seen in **Table 6**.

**Table 6.** Comparison of highest compressive strength at 28 days

| Code | Treatment | Average Compressive Strength (MPa) |
|---|---|---|
| SP4% | Room temperature | 4,92 |
| SP2% | soak | 5,28 |
| PS8% | soak | 6,02 |
| PS4% | Room temperature | 5,81 |

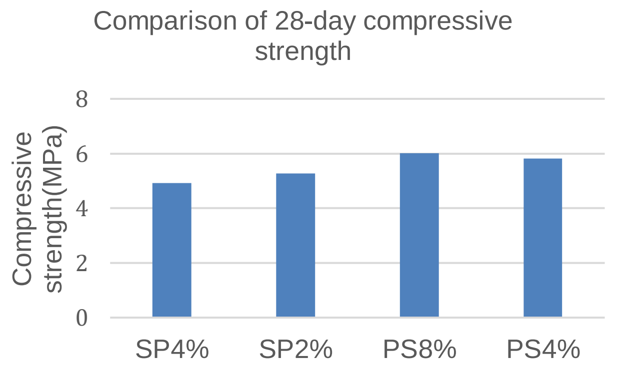


**Figure 11.** Comparison graph of the highest compressive strength values

**Table 6** and **Figure 11** show that the PS4% mortar with a percentage of 0.5% polypropylene fiber and 8% silica fume has the highest compressive strength of 6.02 MPa, and SP4% with a percentage of 1% polypropylene fiber and 4% silica fume has a smaller compressive strength. This shows that the greater the percentage of polypropylene fiber added to the mortar mixture, the lower the compressive strength of the mortar, and the greater the percentage of silica fume added to the mixture, the higher the compressive strength.

From the comparison carried out, the thing that causes the compressive strength to be lower is that adding too much percentage of polypropylene fiber to the mixture will have a negative impact on workability during stirring so that it will decrease. In addition, the addition of silica fume used as a substitute for cement if used too much can reduce compressive strength because silica fume will turn into filler material.

## CONCLUSION

From the results of the compressive strength test it can be concluded that the more percentage contained in the mortar mixture can reduce the compressive strength. This shows that the higher the polypropylene fiber content, the lower the compressive streng. The addition of silica fume to the mortar mix can increase the compressive strength, but if too much fiber is added, it can decrease the compressive strength.

From the results of the compressive strength test on the composition of the mortar mixture, it was found that the use of 0.5% polypropylene fiber was more effective in increasing the compressive strength. The results obtained with room temperature treatment got the highest compressive strength value of 5.81 MPa, and with treatment in water got the highest compressive strength value of 6.02 MPa. Water treatment is more effective than room temperature treatment, as water treatment helps to reduce cracking due to hydration heat release in cement.

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