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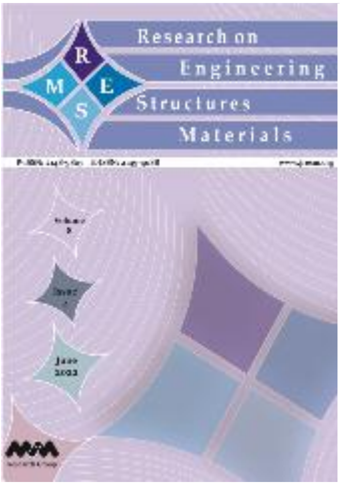

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Research Article

Integral waterproofing concrete mechanical properties with the addition of fly ash

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Abstract

The addition of waterproofing to concrete aims to reduce porosity and is expected to be more watertight. However, the addition of a waterproof layer to the concrete can reduce its performance of the concrete. Therefore, researchers are trying to innovate an integral mixture of waterproofing concrete with fly ash (FA) as a filler. FA added to the integral waterproofing concrete mix is expected to improve its mechanical properties, including the modulus of elasticity. The Madrid Parabola Formula and Desay & Khrisnan Formula are usually used in calculating the stress-strain distribution of concrete. This case aims to determine the physical and mechanical properties as well as the stress-strain distribution equation by adding FA to integral concrete waterproofing. In this study, the specimens used were cylindrical in shape with a size of 15 cm x 30 cm. The ingredients are PPC cement, sand, gravel, 1.5% integral waterproofing added (Damdex brand), and the addition of FA from cement weight 0% to 15% in 5% increment intervals. Tests for compressive strength, split tensile strength, and modulus of elasticity tests were carried out in reference to ASTM C39/C39M-18, 2018, ASTM C 496/C 496M – 04, 2004, and ASTM C 469 – 02, 2002. The results showed that the more FA was added, the more strength increased. The Desay-Khrisnan stress-strain formula is more suitable for this concrete

1. Introduction

Concrete is the result of the bond between the paste (cement and water) with the aggregate. In some conditions, concrete is also required to be waterproof. In project construction, many workers neglect work procedures, which can cause underground structures such as basement walls or floors to leak. This requires high repair costs. Along with the times, the development of concrete technology cannot be avoided. Various kinds of proofs of this innovation have been created, one of which is integral concrete waterproofing and plasticizing admixture[1]-[3]. Waterproofing Essential is made of concrete with average conditions that cannot be waterproofed so that the need for concrete from the concrete mixture can produce waterproof concrete. The addition of waterproofing can make the concrete last longer [4]-[6]. The life of concrete can be durable because the addition of waterproofing materials reduces water absorption and permeability through the concrete capillaries.[3,7, 8]. Standard concrete has a compressive strength that is more significant than the required waterproofing concrete. The integral waterproofing method can drastically reduce concrete's compressive strength. The concrete's compressive value is below the average compressive strength [9]-[12].

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There have been many uses of industrial waste, fly ash (FA), and agricultural residues such as rice husk ash (RHA), and sugarcane bagasse ash (SBA) as a substitute for cement in concrete research[13]-[20]. This material aims to replace the depletion of natural resources and reduce CO2 emissions in the air from cement manufacture, which will help save the environment. Previous research by replacing cement or adding additives from FA, RHA, and SBA can improve the mechanical strength of concrete. In previous studies, this waste as a substitute for paste materials or as aggregates, the mechanical properties of which can be improved with age. At the beginning of the 28th generation, the strength is still low, but after 56 days the strength will be higher or equal to normal concrete. Meanwhile, as a filler, it can improve the mechanical properties of concrete [21]- [24]. In some conditions, FA has a chemical content that can increase the binding element in cement called silica dioxide (SiO_2), thus increasing the compressive strength[25]- [28]. The use of FA material is based on the properties of this material which is similar to cement and can close the pores of the concrete thereby increasing the integral waterproofing strength of the concrete. The similarity of these properties can be seen physically and chemically [29,30]. FA material has very good physical properties, able to pass through a filter of fewer than 50 millimicrons by 5% - 27%, has a specific gravity value of 2.15-2.6 and is gray in color. The most abundant chemical content of FA is usually silica dioxide (SiO_2) with a percentage of up to 80%. Therefore, FA can be an integral filler in concrete waterproofing similar to cement.

The modulus of elasticity is the ratio of stress to strain under elastic conditions, the ability to undergo elastic deformation under applied loads. The greater the value, the greater the stiffness, but the deformation value decreases. From the results of laboratory tests, uniaxial compression tests, researchers can determine the behavior of concrete, its modulus of elasticity, using a parabolic equation of order 2. Draw a straight line measured relative to the horizontal axis with a tangent line twice the tangent. This line can be used as an assumption in calculating the modulus of elasticity of concrete before further numerical analysis is carried out [31]. In calculating the modulus of elasticity, the Madrid parabola equation and the Desay & Krishnan formula are used.

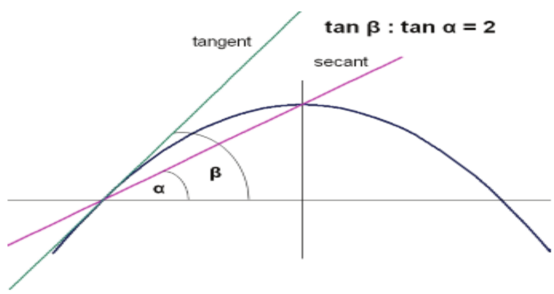

Fig. 1. Property of 2nd order parabola (P.Kmiecik, M.Kaminski)

The formula for the stress-strain relationship for the non-linear behavior of concrete structures is as follows:

- Madrid Parabola

$$\sigma c = Ec.\varepsilon c\,.\left[1 - \frac{1}{2}\left(\frac{\varepsilon c}{\varepsilon c1}\right)\right],\quad \sigma c = f(Ec, \varepsilon c1) \tag{1}$$

- Desay & Krishnan

$$\sigma c = \frac{Ec.\varepsilon c}{1+\left(\frac{\varepsilon c}{\varepsilon c1}\right)^2} \quad , \sigma c = f(Ec, \varepsilon c1) \tag{2}$$

According to ASTM C496 from the test result at the laboratory determined that the modulus elasticity as the ratio of stress when reaching 40% of the stress collapse to the strain following the stress under these conditions :

$$Ec = \frac{(\sigma 2 - \sigma 1)}{(\varepsilon 2 - \varepsilon 1)} \tag{3}$$

Where : E_c = Modulus Elasticity (Mpa)

σ_c = Concrete Stress

σ_{cm} = average compressive strength

σ_2 = Stress equivalent to 40% ultimate stress (Mpa)

σ_1 = Stress value at the time of reaching longitudinal strain, ε_1 (Mpa)

ε_2 = Strain value at stress σ_2

ε_1 = 0,00005

ε_{c1} = strain ε at stress σ_{cm}

This study determines the mechanical properties of watertight concrete with a mixture of integral waterproofing and variations of FA filler from 0% to 15% of the total cement.

2. Experimental Work

2.1. Material

2.1.1. Fly Ash (FA)

PLTU Paiton Probolinggo is a steam power plant in East Java that uses coal as fuel. Combustion waste in the form of fly ash is used in this case. Table 1 contains the chemical content.

Table 1. Properties FA

Physical	
Soecific Gravity	3.07
Checimal Composition (%)	
Silikon dioksida	52,35
Alumnia Oksida	12,11
Ferri Oksida	12,35
Kalsium Oksida	6,79
Magnesium Oksida	10,63
Natrium Oksida	2,15
Sulfur Trioksia	2,27
Water	0,12
LOI	0,40

2.1.2. Aggregates

Lumajang river natural sand from Mount Semeru, East Java, Indonesia, is used as fine aggregate in the concrete mix. The specific gravity is 2.53, the volume weight is 1710 kg/m3, the water absorption rate is 2.78%, and the fineness level is 2.15. Coarse aggregate obtained from crushed stone in Jember. The specific gravity of crushed stone is 2.6, the unit weight is 1390 kg/m3, the water absorption rate is 0.54%, the fineness level is 1.45, and the maximum size is 20 mm. The properties of the aggregates used in this concrete mix are given in Table 2 and Fig. 2

Table 2, Physical and mechanical properties of aggregates.

Unit	Sand	Broken Stone
Specific gravity	2.53	2.6
Volume weight (kg/m^3)	1710	1390
Water absorption (%)	2.78	0.54
Fine Modulus	2.15	1.45
Clay and fine materials (%)	1.54	0.39

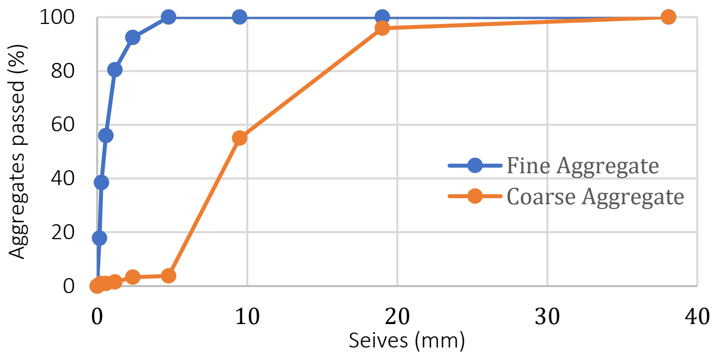

Fig 2. The grading curve of aggregates

2.1.3. Waterproofing

Waterproofing is widely available in building stores (Damdex), which functions as an added ingredient for fresh concrete so that the concrete is water seepage resistant or the concrete is watertight. It is recommended to use 0.5 -2% by weight of cement, in research using 1.5% by weight of cement.

2.2. Mix Desain

To achieve the research objective, a mixture was prepared with three variations of FA, 5%, 10%, and 15% by weight of cement. FA as a filler material in the concrete mixture. The parameters of the mix that remained constant were cement and 1.5% water proofing by weight of cement.

Table 3. Material Requirements per Concrete Cylinder for Each Variation of FA

Sample	% filler FA	Material					
		Cement (Kg)	Water (Ltr)	Sand (Kg)	Gravel (Kg)	FA (Kg)	Waterproofing (kg)
BW	0	3.26	1.30	4.35	6.00	0	0.049
BWF1	5	3.26	1.30	4.35	6.00	0.1629	0.049
BWF2	10	3.26	1.30	4.35	6.00	0.3257	0.049
BWF3	15	3.26	1.30	4.35	6.00	0.4889	0.049

2.3. Testing Procedure

Testing fresh concrete with slump test according to ASTM C143. Concrete testing by compression test according to ASTM C39 split tensile strength according to ASTM C496, Modulus of Elasticity according to ASTM C469, and absorption according to ASTM C642. The test object is cylindrical (15 x 30 cm). Tests were carried out at 28 days of concrete, and an average of five samples were recorded for each test.

3. Results and Discussion

3.1. Workability

Fresh concrete testing was carried out to determine the flowability level using the slump abrams test. In the implementation of mixing, the control variable in this study is the slump abrams test. Therefore, the use of water in the normal concrete mixing process must always be controlled. The addition of FA to the concrete mixture can increase the concrete's workability so that the fresh concrete is thinner. The slump abrams test results on integral waterproofing concrete are presented in Table 4, Fig. 3, and Fig. 4.

In previous studies, FA in a fresh concrete mixture will increase workability and reduce water addition. Such a function allows concrete planning by reducing the lower cement water factor ratio for equal workability, useful in increased strength, tighter pore structure, and increased durability. In the previous test, the relationship between the slump and FA test at the same water content shows that it is directly proportional, where the more FA additions will also show a high slump test value

Fig. 3. Slump Abrams Test Measurement on BW, BWF1, BWF2, and BWF3

Table 4. Abrams slump test results on fresh concrete

Sample	Slump test (cm)
BW	10
BWF1	10
BWF2	11
BWF3	12

Figure 4 shows the integral waterproofing (BWF) slump value of FA. As the FA value increases, the slump value also increases. Increasing slump value will give affect the performance of fresh concrete, high workability, and low viscosity.

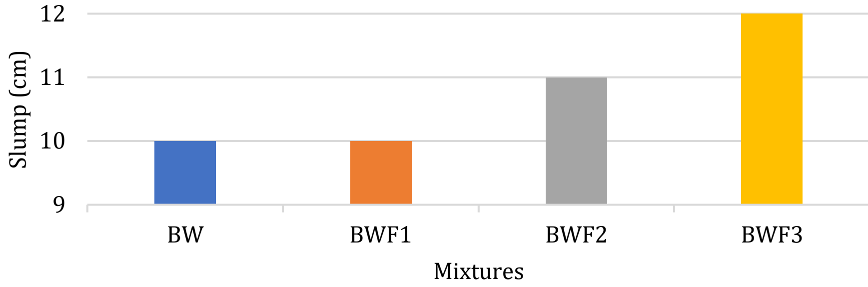

Fig. 4. Slump test value

3.2. Compressive strength

The addition of 0% to 15% FA by weight of cement into 1.5% integral watertight concrete will be tested for strength. The compressive strength of the prepared BW samples increased directly proportional to the addition of FA. Fig. 5 shows the strength of the sample at 28 days of age. Compared with the reference sample, namely BW, the BWF sample has a higher strength. With the addition of FA to BW it will close or reduce the pore size. With the FA bond polymerization process, a pozzolanic reaction is formed which contributes to increase strength of BW.

Table 5. Compressive strength

Sample	MPa
BW	33.32
BWF1	35.48
BWF2	38.69
BWF3	43.22

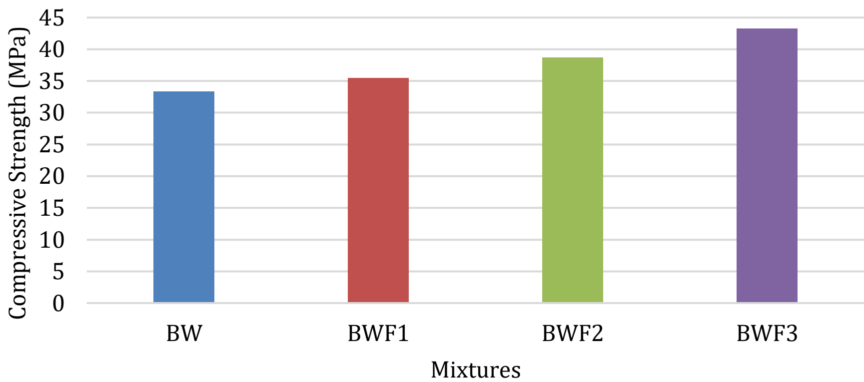

Fig. 5. Effect of addition FA on Compressive Strength BWF

The relationship between the increase in compressive strength and the increase in the number of FA is very strong. The correlation coefficient for the linear relationship is R2=0.9747 according to Eq. (4)

$$y = 3.291x + 29.45 \tag{4}$$

From this relationship, the increase in compressive strength is directly related to the addition of FA, this causes the compressive strength to increase as a result of the reduced pore size of the concrete

3.3. Splitting Tensile Strength

In this case, the split tensile strength of BW with the addition of FA will be plotted in Figure 6. The highest split tensile strength value was obtained in the BWF3 composition with an FA content of 15%, with a split tensile strength value of 3.11 MPa. While the lowest split tensile strength value is in the BWF0 composition with 0% FA content with a split tensile strength of 3.04 MPa. This means that the addition of fly ash as a filler can increase the value of the split tensile strength of integral waterproofing concrete because adding fly ash as a filler or added material can improve the mechanical properties of concrete.

Table 6. Splitting tensile strength

Sample	MPa
BW	3.04
BWF1	3.07
BWF2	3.09
BWF3	3.11

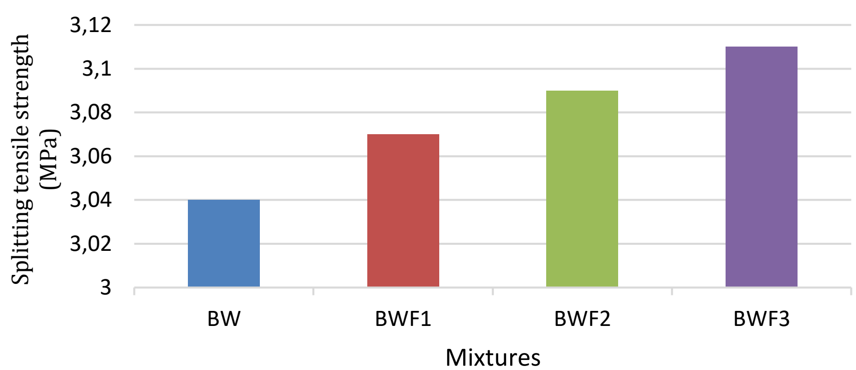

Fig. 6. Effect of addition FA on Splitting tensile Strength BWF

3.4. Modulus of Elasticity

Testing the modulus of elasticity of concrete was carried out on all samples of specimens used for compressive strength at the age of 28 days. The modulus of elasticity test is carried out until the concrete is completely destroyed. The results of the Stress–Strain test will be presented in Fig. 8, and the maximum average stress and strain can be seen in table 7. to get the value of the elastic modulus using Eq. (3)

Table 7. Strain (ε_{c1}) values Strain value of waterproofing integral concrete

Sample	σ_{cm} (MPa)	ε_{c1}(mm/mm)
BW	33.32	0.0017
BWF1	35.48	0.0021
BWF2	38.69	0.0027
BWF3	43.22	0.0029

Fig. 7. The setting for testing modulus of elasticity

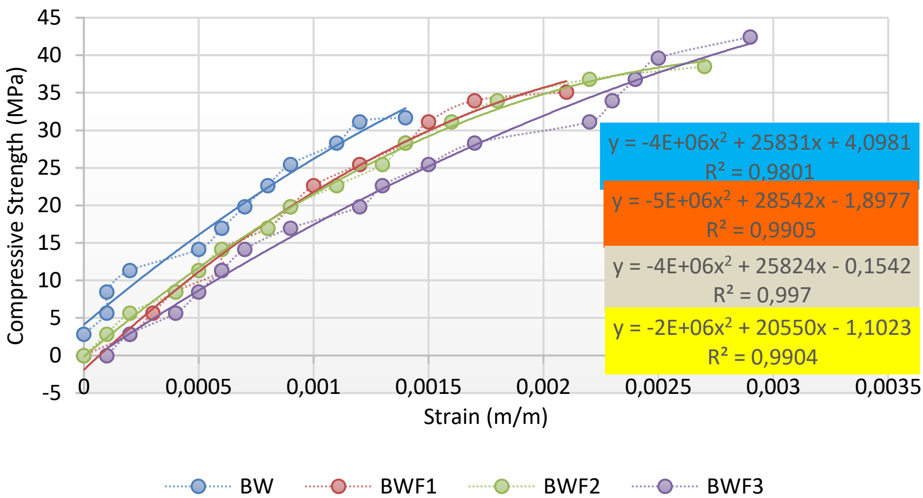

Fig. 8. Stress-strain diagram of 2nd order parabolic integral waterproofing concrete with additional FA variation

Fig. 8. shows the stress-strain relationship diagram of 2nd-order parabolic integral waterproofing concrete with an additional FA variation. To approach the σc-Ɛc relationship using the Madrid parabola equation and Desay & Krishnan. In analyzing the modulus of elasticity follow the following steps (example BW):

- It is assumed from the second-order parabolic equation that the value of Ec = 39.743,647 MPa at σ_{cm} = 33,32 MPa. The value of Ec is obtained from the tangent twice the tangent to the angle formed by the line through the point (σ_{cm}, ε_{c1})
- From the Ec above, it is graphed from the Madrid Parabola equation and the Desay & Krisnan equation
- Determine the stress value σ_1 at 0.00005 strain and determine the strain σ_2 at 0.4 σ_{cm}
- The new modulus of elasticity is obtained tangent from the straight line passing through (ε_{c2}, 0.4 σ_{cm}) and (0.00005, σ_1), Ec = 34.680,189 MPa (Parabola Madrid), Ec= 37.818,252 MPa (Desay & Krisnan)

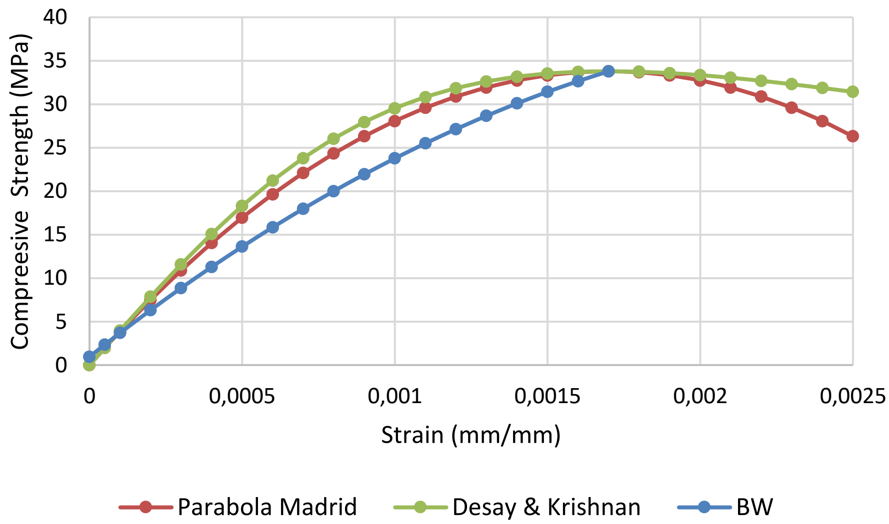

Fig. 9. Comparison of stress-strain diagram between BW concrete with Madrid Parabola and Desay & Krishnan

From the above calculation, the elastic modulus of waterproofing concrete with the addition of FA is obtained which is close to the Desay & Krishnan equation. Table 5. shows the value of the elastic modulus of several equations. With a proportion of 1.5%. Integral waterproofing concrete mix with fly ash filler variation of 0% to 15% differs from 28779.60 MPa to 37818.252 MPa (Desay & Krishnan). The results of the highest modulus of elasticity obtained the proportion of mixed waterproofing 1.5% with 0% fly ash filler. With the addition of fly ash, the behavior of the concrete will be more ductile. While the smallest elastic modulus was obtained compared to 1.5% waterproofing with 10% fly ash variation, on 1.5% fly ash variation the elastic modulus increased again. That the improvement of fly ash as an integral filler of waterproofing concrete can improve the behavior of concrete, increase its ductility and strength.[32,33]

The effect of fly ash composition on the modulus of elasticity of integral waterproofing concrete is shown in Figure 6. The equation obtained from this relationship is $y = 52.893X^2 - 1411.6X + 37573$ with R2 = 0.9908. The addition of fly ash to the integral waterproofing concrete increases the performance of the waterproof concrete.[34,35]

Table 8. Modulus of Elasticity of Integral Waterproofing Concrete (MPa)

Sample	Ec = Tan β = 2 x Tan α	Parabola Madrid	Desay & Krishnan
BW	39743.647	34680.189	37818.252
BWF1	34276.667	30005.633	32664.106
BWF2	29933.778	26282.965	28589.563
BWF3	30127.034	26471.950	28779.605

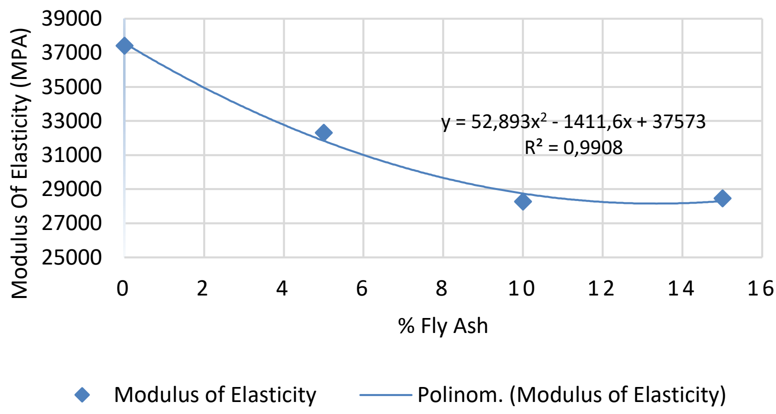

Fig. 10. Modulus of elasticity relationship with integral waterproofing concrete with the addition of fly ash

4. Conclusions

Several discussions about the integral waterproofing concrete result in decreased strength compared to normal concrete. This paper discusses the possibility of increasing the mechanical properties of integral waterproofing concrete with the addition of fly ash regarding the workability, strength, and modulus of elasticity of concrete. From this paper it can be concluded:

- The addition of FA is directly proportional to the slump value, with the highest slump value at 12 cm at 15% FA content (BWF3). The addition of fly ash to concrete waterproofing improves workability because the particle size is mostly spherical, resulting in better traceability.
- The use of 15% FA produces a compressive strength of 43.32 MPa, and an increase of 29.71% from integral concrete waterproofing without FA (BW) of 33.32 MPa. The polymerization process of silica on FA to form geopolymer chains is very important so that strong bonds in the polymer chains can reduce the pore diameter can increase their strength.
- BWF3 produces the highest split tensile strength of the others at 3.11 MPa and an increase of 2.3% compared to BW, which had a tensile strength of 3.04 MPa.
- The shape of the stress-strain relationship in the test with the FA variation tends to be close to the equation proposed by Desay & Khrisnan
- The greatest ultimate strain value occurs in BWF3 of 0.0029 mm/mm, and the lowest is in BW of 0.0017 mm/mm
- The elastic modulus values of BW, BWF1, BWF2, and BWF3 were 37818.252 MPa, 32664.106 MPa, 28589.563 MPa, and 28779.605 MPa respectively.

This conclusion reveals that it is possible to incorporate FA into construction and building materials using waterproofing, without significant changes to its mechanical properties, especially compressive strength. FA additives are cheaper than the addition of original portland cement or silica fume additives in maintaining the compressive strength of concrete by using waterproofing such as normal concrete compressive strength.[36]

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