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Durability of Ecofriendly Roller Compacted Concrete Pavement

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Abstract— **Roller-compacted concrete (RCC) is a type of concrete that is compacted using a roller in the field. RCC usually uses cement and water as a binder, which increases carbon dioxide (CO_2) in the environment. This study uses fly ash as a mixture of concrete and sodium sulfate for Ecofriendly Roller Compacted Concrete Pavement (ERCCP) immersion. The cylindrical specimens 150 mm x 300 mm to examine compressive strength, and the flexural strength specimens were 150 x 150 x 500 mm^3 using fly ash 0%, 10%, and 15%. The concrete cured in plain water and sodium sulfate solution at the age of 14 days and 28 days. The optimum compressive strength result is 54.90 Mpa using 10% fly ash and 28 days in water curing. The highest modulus of elasticity is 1440.23 Mpa with the addition of 15% fly ash at 28 days. The maximum flexural strength is 4.56 Mpa.**

Keywords—Roller Compacted Concrete, fly ash, sodium sulfate, compressive strength, curing

I. INTRODUCTION

Roller-compacted concrete (RCC) is a cost-effective and quick to construct option for various pavement applications. It has typically been utilized in areas with heavy loads and low-speed traffic[1]. RCC is an expeditiously evolving concrete material and construction methodology. Its distinct characteristics make it widely applicable in various engineering fields, from hydraulic structures to pavements. Originally based on soil compaction methods, RCC has developed considerably, providing notable engineering advantages and cost efficiency. Due to its unique macro and microstructure. RCC sometimes behaves as an unconventional material[2].

Roller-compacted concrete (RCC) is a dry mixture composed of the same constituents as conventional concrete, but in varying amounts. Its construction process, however, differs significantly from conventional concrete in pavement applications. Because of its moisture content, RCC requires heavy vibratory steel drum rollers and rubber-tired rollers for compaction into its final shape. While concrete strength largely relies on hydration, the compaction process greatly increases RCC's density, improving its load-bearing capacity and strength[3]. RCC pavements are robust, dense, and long-lasting. These qualities, along with the advantages of fast construction and cost-effectiveness, make RCC pavements an ideal choice for parking lots, storage zones, ports, intermodal and military facilities, highway shoulders, streets, and highways[4]. The compatibility of RCC depends on fine aggregate content, though to less than water content. Mixtures of RCC are less prone to segregation during moving and placement when the fine aggregate content is beyond the recommended amount for conventional concrete mixes[5]. Compaction of RCC mixtures can benefit from the use of fly ash (Class F or C) and water-reducing and retarding additives. Still, the particular composition of the mix determines how effective these materials are. ACI 207.5R [6] states that mixtures with measured consistency can utilize less water when fly ash is substituted for some of the cement. To improve the workability and density of RCC, fly ash can also be used as a mineral filler in combinations with low paste volumes.

The durability of RCC pavement can be assessed through various methods, including its abrasion resistance, resistance to sulfate attack, water penetration, and porosity[7]. When sulfate-resisting portland cement instead of regular portland cement, RCC mixes resistance to sulfate attack test cycles increased. Additionally, samples exposed to 60 cycles and containing sulfate-resisting cement had greater modulus of rapture by 17.227% at 16% than the resistivity of samples containing regular portland cement composition.[8]. The sulfate resists for high strength concrete better than the low strength concrete. Because the low concrete, the formation of gypsum and ettringite during the sulfate attack caused a loss of bond between the cement paste and aggregate leading to cracking of concrete[9]. This research will investigate the resistance of Ecofriendly Roller Compacted Concrete Pavement (ERCCP) to sulfate attack in terms of compressive strength and flexural strength with variations in the percentage of fly ash and days immersion.

II. MEASUREMENT OF COMPRESSIVE STRENGTH

A. Sample Preparation

Roller Compacted Concrete compressive strength is tested using the cylindrical mold that meets the criteria of specification C470/C470M, with a diameter of 150 mm and a height of 300 mm, highly reusable molds[10]. The specimens are compacted following ASTM C1435[11]. A vibrating compaction hammer with a mass of 10.6 kg excluding the tamping plate and shaft. It must possess a minimum power input of 900 W and be capable of delivering 2000± 200 impact per minute. The cylindrical test is compacted with a vibrator hammer in three layers of 20 seconds duration per layer. The flexural strength is tested using specimens 150 mm x 150 mm x 500 mm.

Figure 1. Vibrator Compaction Hammer

The materials used were fine aggregate from Progo and Merapi, coarse aggregate from Progo and Clereng, Yogyakarta Indonesia, and cementitious materials consisting of Portland composite cement than superplasticizer, water and class F fly ash from Tanjung Jati B steam power plant, Jepara, Indonesia. Fly ash which is waste from combustion in steam power plants.

B. Testing Procedure

Digital Compression Testing Machines: These machines provide precise and automated loading mechanisms to break ERCCP specimens and determine peak compressive strength with high accuracy. This machine is equipped with a Linear Variable Differential Transformer (LVDT) to measure the displacement or deformation in ERCCP when given a compressive load. This measurement is important to know how ERCCP material changes shape under pressure. This tool has a high sensitivity in measuring minimal changes, thus providing more accurate measurement results than manual methods. Deformation data generated by LVDT can be calculated as modulus elasticity of ERCCP, which is an indicator of the strength and resistance of ERCCP to load.

Figure 2. Digital Compression Testing Machine

The flexural test using third point loading according to ASTM C78/C78M-18[12]. Flexural test to determine maximum flexural load and deflection. The flexural test setup shows as Fig 3.

Figure 3. Flexural Testing

C. Mix Design Optimization

Aggregate Selection: The type, size, and grading of aggregates play a significant role in optimizing the compressive strength of ERCCP. Using well-graded, angular aggregates enhances interlock and compaction. This research uses a maximum fine aggregate gradation size of 4.75 mm and a maximum coarse aggregate size of 19 mm. Superplasticizer was 0.5% by weight of cement and fly ash varied at 0%, 10%, and 15% by weight of cement. Mix design based on Indonesian Standard SNI 7656:2012[13] and modification from several journals. Materials composition as shown in Table 1. This research used 36 specimens, curried in plain water and sodium sulfate solution (Na_2SO_4) for a period of 14 and 28 days as shown in Table 2. Sodium sulfate exposure testing uses the ASTM C1012 test method, with a concentration of each liter of sodium sulfate (Na_2SO_4) solution of 5% or equal to 50 grams dissolved in 1000 ml of water. Mix the solution the day before use, cover, and store at a temperature of 23.0 ± 2.0 ^oC[14].

TABLE I. MATERIAL COMPOSITION FOR 1M^3

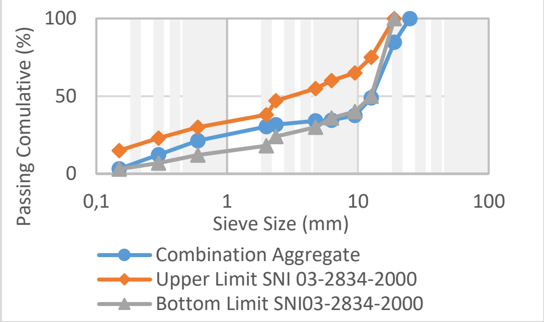
Composition	Amount (Kg)		
	RCC 0	**RCC 10**	**RCC 15**
Cement	349,8	311	291
Fine Aggregate Progo	300.43	300.43	300.43
Fine Aggregate Merapi	300.43	300.43	300.43
Coarse Aggregate Clereng	583.19	583.19	583.19
Coarse Aggregate Progo	583.19	583.19	583.19
Water	190	190	190
Fly Ash	0	38.2	58.2
Superplasticzer	1,94	1,94	1,94

TABLE II. VARIATION OF OBJECT

Specimen	Fly Ash (%)	Age (Days)	Curing	Amount
ERCCP 0-B14	0	14	Plain Water	3
ERCCP 0-S14			Sodium Sulfate	3
ERCCP 0-B28		28	Plain Water	3
ERCCP 0 -S28			Sodium Sulfate	3
ERCCP 10-B14	10	14	Plain Water	3
ERCCP 10-S14			Sodium Sulfate	3
ERCCP 10 -B28		28	Plain Water	3
ERCCP 10-S28			Sodium Sulfate	3
ERCPC 15-B14	15	14	Plain Water	3
ERCCP 15-S14			Sodium Sulfate	3
ERCCP 15-B28		28	Plain Water	3
ERCCP 15-S28			Sodium Sulfate	3

III. RESULT AND DISCUSSION

Combined aggregate result between fine aggregate and coarse aggregate as shown in Fig 4. The upper and lower limits of combined gradation are based on Indonesian Standard SNI 03-2834-2000[15].



.Figure 4. Combined Aggregate Gradation

The compression strength result, as shown in Fig 5, shows that ERCCP compressive strength at 28 days is 54.90 Mpa with the addition of 10% fly ash in the usual water curing higher than 0% and 15 %. This is in accordance with the result of Rajiman et al that concrete with 10% fly ash showed optimal compressive strength values, while higher proportions caused a significant decrease without sulfate immersion[16]. The lowest ERCCP compression strength was 36.22 Mpa at the age of 14 days with the addition of 10% fly ash in sulfate solution immersion. In sulfate immersion, the strength tends to decrease; this occurs due to the reaction between sulfate ions with calcium hydroxide ($Ca(OH)_2$) and calcium aluminate hydrate (C3A). Calcium hydroxide readily reacts with sulfate to form products that can damage ERCCP, such as etringite and gypsum[17]. Based on research from Bayqra et al.[18], by partially substituting fly ash for cement, the ideal water/binder ratio was raised, which in turn enhanced water absorption and reduced mix strength.

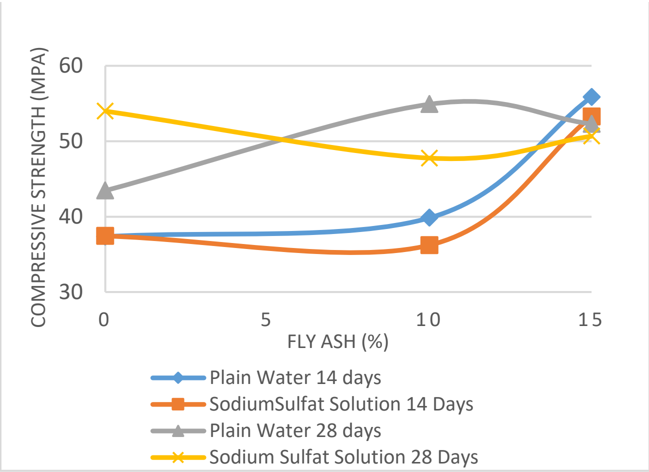


Figure 5. Compressive Strength

The modulus of elasticity is the ratio between strain and stress in elastic changes in shape or measure of the strength/stiffness of a material that can change shape and, return to its original state when given a load/force[19]. The modulus of elasticity in concrete is influenced by the type of aggregate used, the temperature of the test object, the water content, the ambient temperature and the age of the concrete[20]. Figure 6 shows that the highest modulus of elasticity is 1440.23 Mpa with the addition of 15% fly ash at 28 days. The modulus elasticity of ERCCP at 14 days is lower than that at 28 days.

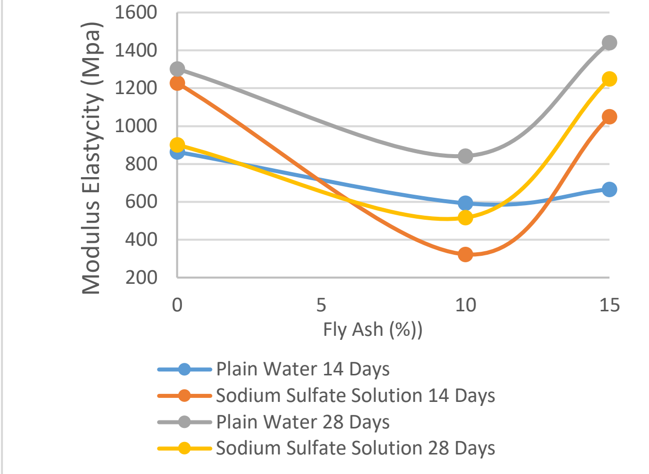


Figure 6. Modulus Elasticity

The test result of flexural test shows that the replacement of 10% fly ash decreases the flexural strength and the replacement of 15% fly ash increases flexural strength (Fig.7). Because the proportion of 10% fly ash not being sufficient to fill the concrete during compaction. According to [4] the flexural strength generally from 3.5 to 7 Mpa.

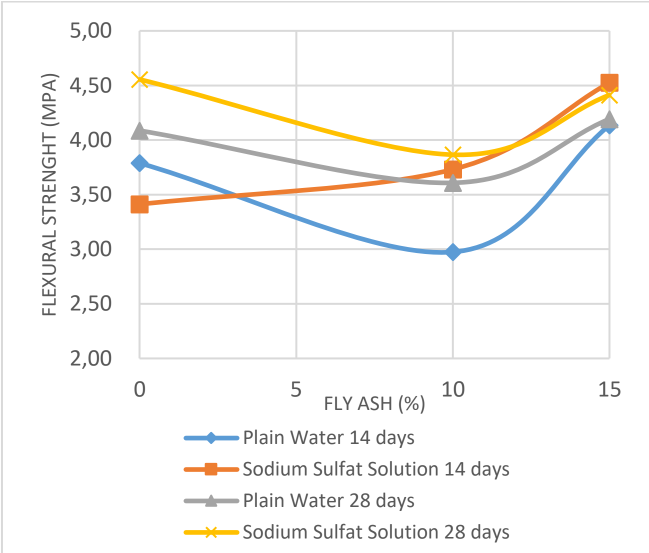


Figure 7. Flexural Strength

IV. Conclussion

1). Compressive strength of ERCCP with fly ash 10% at 14 days lower than fly ash 0% and 15%.

2). The decrease in compressive strength of sulfate immersion ERCCP compared to plain water at the age of 14 days for 10%, and 15% fly ash variation was 10.00%, and 4.88%.Whereas at the age of 28 days the decrease in compressive strength was 14.96% and 3.24%.

3). The use of 15% fly ash is able to reduce the decrease in compressive strength of sulfate immerse ERCCP.

4). The flexural strength of ERCCP maximum was 4.56 Mpa for 28 days with sodium sulfate solution immersion.

5). The use of portland composite cement can produce ERCCP with lower modulus elasticity at the initial age of the ERCCP. However, over time, the modulus elasticity will increase. Due to the slower and gradual hydration process of the pozzolanic component.

6). Sodium sulfate immersion reduce the compressive strength, modulus elasticity, and flexural strength of ERCCP replaced 10% fly ash.

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