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Analysis of the Use of Fly Ash Variations as a Partial Cement Substitute for Roller Compacted Concrete (RCC) Mixtures †

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Abstract: Roller compacted concrete (RCC) is a relatively stiff concrete mixture generally designed with a zero-slump value and compacted with a vibratory roller. It is commonly used in pavement construction. To reduce the utilization of cement, this study employs fly ash at variations of 0%, 40%, and 50% as cement replacements to study fresh concrete's workability and the hardened concrete's mechanical properties. The workability of fresh concrete coming from the vebe test result shows that all the mixtures, according to Brownsville TX, meet the workability criteria as RCC. Moreover, it is concluded that using fly ash as a partial replacement for cement has a positive impact on the compressive strength and splitting tensile strength of concrete.

Keywords: RCC; fly ash; vebe time test; compressive strength; splitting tensile strength

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1. Introduction

Concrete is one of the various choices of basic structural materials in building construction where the mixture of materials includes coarse and fine aggregates, water, cement, and, occasionally, admixtures, where needed [1]. In Indonesia, there is a significant use of rigid pavement with concrete being the basic material used, which also requires reinforcement, thereby prolonging the construction time [2]. Therefore, there is a significant need for a type of concrete that takes a shorter work time along with the development of concrete technology. One of the innovations in concrete technology for road construction is roller compacted concrete (RCC).

RCC is a type of concrete that is compacted with a roller tool and generally designed with a zero-slump value. Some concrete types are defined as RCC due to different ratio usage in mixing even though they basically use the same ingredients as conventional concrete [3]. RCC mixture must be made dry enough so that the compactor does not sink, but also wet enough so that the mortar can be applied evenly during mixing and compaction. RCC pavement is cost-effective and low maintenance.

According to Srinivas et al. [4], composite material properties of concrete are greatly influenced by the interaction between its constituent components, where cement is the main component even though its contribution is only 7–15% of the mixture. Cement plays a crucial role because of its binding properties, but its excessive use has a negative impact on the environment. According to Davidovits [5], the result of the cement production process is CO_2 emission gas, with an amount proportional to the cement production results. Currently, many studies related to concrete technology are carried out to minimize the use

of cement, one of which is related to the utilization of waste materials. The type of waste that can replace cement in the concrete mixture is fly ash, which comes from steam-electric power stations that use coal as the primary energy. SNI [6] states that coal fly ash is a byproduct of coal combustion in a steam power plant furnace with spherical shape and pozzolanic properties. This waste material has the size of fine grains with a grayish color.

Some of the chemical compositions in fly ash are silica (SiO_2), alumina (Al_2O_3), ferrous oxide (Fe_2O_3), and calcium oxide (CaO), as well as other additional elements such as magnesium oxide (MgO), titanium oxide (TiO_2), alkaline (Na_2O and K_2O), sulfur trioxide (SO_3), phosphorus oxide (P_2O_5), and carbon.

In making concrete, fly ash has an effect in causing the occurrence of a free lime binding reaction created during the cement hydration process by silica. In addition, fly ash increases the compressive strength of the concrete because it fills every cavity when making concrete due to its fine particle composition. This makes it more watertight and prevents fine cracks on the concrete surface.

This study uses class F fly ash from the Paiton steam-electric power station in East Java, Indonesia. It was found that this power station produces up to 1,000,000 tons of fly ash waste yearly. This much fly ash cannot be disposed of openly in the environment without causing extreme pollution of the atmosphere since it contains toxic elements such as arsenic, vanadium, antimony, boron, and chromium [7]. Fly ash from the above power plant is classified as F because the silica oxide content is more than 54.9% and contains less than 10% CaO. This fly ash is produced by burning anthracite and new coal bitumen, allowing it to replace cement because of its pozzolanic properties [8].

In the research of Mardani-Aghabaglou et al. [9], they tested the effect of fly ash on the mechanical properties of concrete with variations in the use of fly ash of 20%, 40%, and 60% at a total cement amount of 250 kg/m^3. The results of the analysis of mechanical properties of concrete with a cube-shaped sample measuring 15 cm $\times$ 15 cm obtained optimal compressive strength at a variation of 20% with a compressive strength of 38.90 MPa at the age of 28 days. This occurs because fly ash is a supplementary material in concrete used as a filler. It increases internal adhesion and can reduce the porosity of the transition zone, which is the smallest area in concrete, and produces concrete with better bearing capacity.

Conventional compaction and concrete workability test methods are unsuitable for evaluating fresh RCC mixtures [10]. RCC workability is determined by measuring the time required to consolidate the volume of roller compacted concrete through vebe time testing. Furthermore, adequate workability is necessary for roller compacted concrete for easy compaction, uniform density, bonding with previously placed layers, and to support compaction equipment. The paste of the mixture greatly influences RCC workability. According to Dale Harrington [11], the mineral aggregates make up 85% of the volume of RCC and play an essential role in achieving the required workability since fly ash adds minerals to the mixture, producing fine granules. The main parameters of this experimental study are concrete compressive strength and splitting tensile strength.

According to Scanlon et al. [12], compressive strength testing is used to meet design strength requirements. Also, it acts as an indicator of the mechanical properties of concrete, such as durability for road pavements. The splitting tensile strength of concrete is also an essential factor to be tested because RCC is unreinforced concrete; therefore, the splitting tensile strength test helps to plan the thickness of the road pavement to be made. According to research conducted by Chhorn et al. [13], RCC's splitting tensile strength value is usually lower than conventional concrete to be in line with conventional concrete. Previous studies have attempted to improve the quality of concrete [14]. However, not many researchers discuss the use of fly ash to replace cement to enhance the quality of the RCC mixture.

Therefore, there is a need to study fly ash variations as a substitute for cement based on the vebe time, compressive strength, and splitting tensile strength. Based on the above introduction, this study was conducted to analyze the effect of variations in the use of fly ash of 0%, 40%, and 50% as a substitute for cement in RCC at the age of 28 days. This study aims to experimentally produce roller compacted concrete (RCC) with higher compressive strength than conventional concrete, which meets the ACI.325.10R standard requirement and is eligible and accepted for road paving construction [15].

This study used the standard practice of making and molding RCC in cylinder molds using a vibrating hammer [16,17]. Test specimens were developed by adding fly ash with variations of 0%, 40%, and 50% to produce 15 cm × 30 cm cylinder test specimens.

The approach used in this study is experimental and is developed to provide answers to researchers of RCC in Indonesia by conducting several tests such as vebe time tests, compressive strength, and splitting tensile strength of concrete.

2. Materials and Method

This study uses an experimental approach methodology to evaluate the relationship between variables in the experiment. This study was conducted by developing research that has been carried out on road paving applications of RCC with the use of Fly Ash in percentages of 0%, 40%, and 50%.

The concrete mix design in this study used guidelines from Brownsville, TX. Table 1 shows the RCC mix design used in this study. The mix design was carried out to produce $f_{c'}$ = 30 MPa.

Table 1. RCC mix proportion per m^3 for design strength f_c' = 30 MPa.

Type of Concrete	w/b	Cement	Fine Aggregate	Coarse Aggregate	Water	Fly Ash
		(kg)	(kg)	(kg)	(kg)	(kg)
RCC-FA 0%	0.47	299.01	1045.35	763.55	140.01	-
RCC-FA 40%	0.47	179,41	1045.35	763.55	140.01	119.61
RCC-FA 50%	0.47	149.51	1045.35	763.55	140.01	149.51

The materials such as fine and coarse aggregates were obtained from PT. Pancadarma Beton Ready-mix in Karanganyar, Indonesia and fly ash was obtained from PT. Solusi Bangun Beton, located in Yogyakarta, Indonesia. All of these materials have been tested for quality to meet the requirements for concrete mix design. To test the strength of the concrete, a 15 cm × 30 cm cylindrical test specimen was used. The concrete was molded in the formwork for 24 h and then released. Furthermore, the concrete cylinder was soaked in plain water for 28 days to test the compressive strength and splitting tensile strength. The results of the roller compacted concrete mix design are shown in Table 1.

Concrete Making Method

RCC ingredients were stirred until they became fresh concrete, after which the consistency of the mixture was tested using vebe time. This is performed because the concrete's RCC mixture has a low water binder ratio (w/b) and leads to zero slumps of fresh concrete, which means a slump test cannot be carried out to determine the consistency of the mixture.

Figure 1 shows the compaction of roller concrete in the laboratory using a vibrating hammer. This is performed by molding fresh concrete into a cylindrical mold using an electric vibrating hammer equipped with a shaft and a round end plate.



Figure 1. Roller compacted concrete compaction with vibrating hammer.

Unlike laboratory experiments, compaction in the field is carried out using a roller machine based on the ASTM C1435 instructions on making RCC [16]. Maintenance of RCC specimens is the same as conventional concrete whereby soaking inside plain water is required for 28 days followed by mechanical testing of the cured concrete.

The results of making conventional concrete with the same mixture as the control RCC have a different physical form from the RCC compacted with a vibrating hammer. This happens because the compaction of conventional concrete is performed by ramming with a steel rod which leads to uneven distribution of concrete in the mold. This leads to porous concrete due to the existence of many cavities in the concrete [18].

Conventional concrete test specimens also have a specific gravity of 1.900 kg/cm^3 that is 20.44% lighter than control RCC with an average specific gravity of 2.389 kg/cm^3 [19]. Figure 2 shows the physical form of RCC and conventional concrete and the differences between the two types.



(**a**) RCC specimens compacting with vibrating hammer



(**b**) RCC specimens compacting without vibrating hammer

Figure 2. Physical comparison of roller compacted concrete test specimens.

3. Result and Discussion

3.1. Vebe Time Test

Vebe time test is conducted at the fresh concrete stage before the concrete mixture is molded. This test uses a vebe time tool to measure the traceability (workability) of the RCC mixture [20]. The designed vebe time in this study is 30–40 s. Figure 3 below shows the results of the vebe time test.

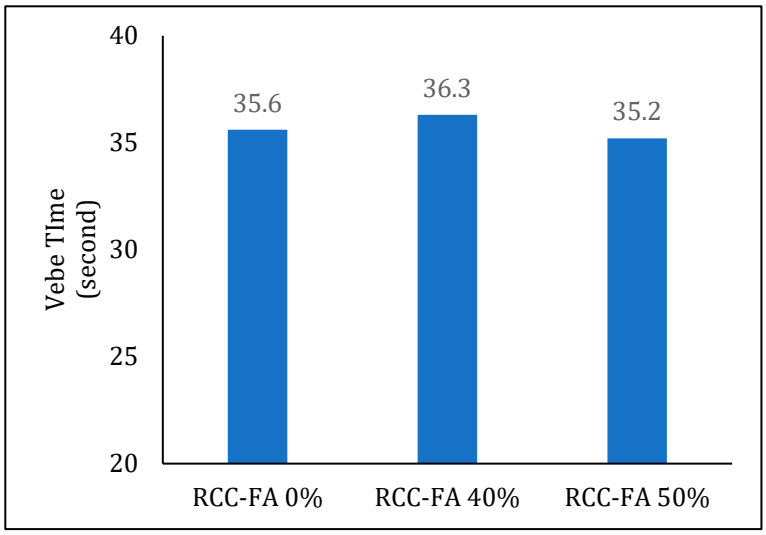

Figure 3. Vebe time testing graph for compacted concrete roller.

Vebe time test with a variation in partial cement replacement of 0% fly ash obtained a vebe time of 35.60 s, whereas a variation of 40% fly ash obtained a vebe time of 36.30 s. The last variation in partial cement replacement of 50% fly ash obtained a vebe time of 35.20 s. The results vebe time as shown in Figure 3 meets the requirements for planning the manufacture of RCC in the laboratory based on ACI 325.10, which falls between 30 and 40 s.

In this study, the vebe time was also tested on conventional concrete with the same mixture. The results of the conventional concrete vebe time showed to be the same as the vebe time of the control RCC.

Research conducted by Setiawati [21] showed that the vebe time value of 15–20 s with the use of 60–70% fly ash variation. Another study conducted by Khayat et al. [3] showed that the workability of concrete should generally be between 40 and 90 s when working with RCC in the field. In the study conducted in a laboratory, a modification of the vebe time value was required in order to have the time in the acceptable range of 30–40 s as required by ACI [22].

Factors affecting vebe time are the operator, type of equipment, and also the procedure followed. The study conducted on the Rehabilitation of the Victoria Dam shows the consistency of the vebe time value of RCC ranges from 15 to 20 s in the laboratory. In the field, the water content of RCC decreases and the consistency increases to around 35–45 s.

If the vebe time value does not match the planning, then there is something wrong with the mixture proportion or the tools do not meet the requirements. Other studies show that RCC is different from conventional concrete in terms of the consistency required which has a direct influence on the mixture proportion requirements [23].

3.2. Compressive Strength Test

3.2.1. Comparison of Vibrating Hammer Compaction with Normal Concrete Compaction on RCC Mixture

Cylindrical test specimens measuring 150 mm × 300 mm with a total of 9 samples were used in this study to conduct compressive strength tests. The test was carried out after a 28-day curing process with a planned compressive strength of 30 MPa [24]. The concrete cylinder test used is a Universal Testing Machine (UTM) at the Civil Engineering Laboratory of the Muhammadiyah University of Surakarta. Figure 4 shows the results obtained in a compressive strength test between RCC and normal concrete.

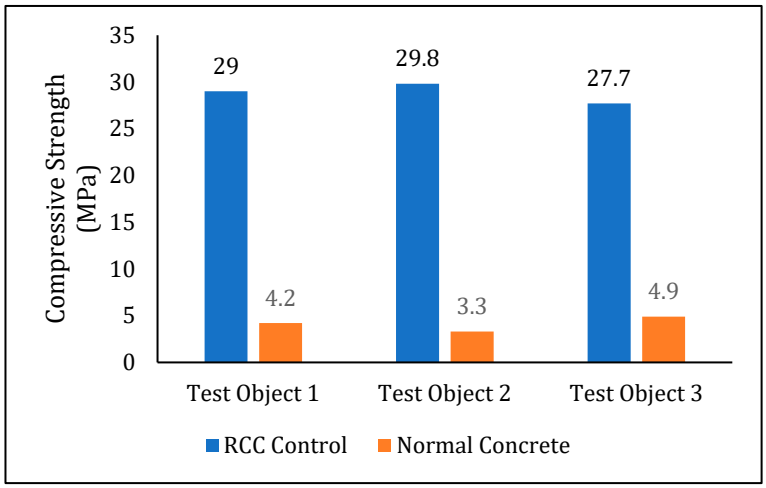

Figure 4. Comparison graph of the results of the compressive strength test of roller compacted control concrete with normal concrete.

The results of the compressive strength of normal concrete with the same mixture as the RCC control were an average of 4.13 MPa at 28 days, a result that is quite far compared to the RCC control using vibrating hammer compaction. This happens because of poor compaction in normal concrete, leading to pores and cavities leading to a decrease in the concrete strength value [25]. This is in line with research conducted by Chhorn et al. [25], where the strength of both RCC and normal concrete depends on many factors, one of which is concrete compaction. Studies show that the compaction process has an important role in the load-bearing capacity of concrete, in general, and especially for RCC because it causes friction between aggregates or particles that can affect the strength of the concrete [26,27].

From the compressive strength results obtained, it can be concluded that the RCC mixture compacted using the normal concrete compaction method does not meet the required compressive strength and, therefore, cannot be used in road pavement. However, the RCC mixture compacted using a vibrating hammer meets the required compressive strength of 28.8 Mpa. The regulation by the ACI 325.10R standard is that the compressive strength value on road pavements on RCC should range from 28 to 41 MPa.

3.2.2. Roller Compacted Concrete Compressive Strength Tests Using Variations in Fly Ash

From Figure 5, the results show that at 28 days, with fly ash at 0%, the compressive strength of RCC was 28.83 MPa. With a 40% fly ash substitution, RCC's compressive strength was 29.66 MPa, whereas a compressive strength of 28.83 MPa was obtained from a 50% fly ash substitution. Results show that the compressive strength increases when fly ash substitution is at 40%, while decreasing at 50%. Therefore, the optimum compressive strength is obtained at 40% of fly ash.

It can be concluded that, with a 30.40 MPa, fly ash variations of 40% meet the compressive strength prediction of 30 MPa. This figure is above the minimum compressive strength standard of 27.6 MPa required for RCC road pavement according to ACI 325.10R.

There was a percentage increase in compressive strength of 5.26% with a 40% fly ash substitution. This is because fly ash is denser and fills all the cavities in concrete thanks to its characteristic of very fine grains. Studies show that the increase is due to the SiO_2 compound in fly ash interacting with the remaining free lime compound Ca $(OH)_2$ from the hydration process. This reaction forms a new compound tobermorite ($C_3S_2H_3$), which causes an increase in the strength of concrete.

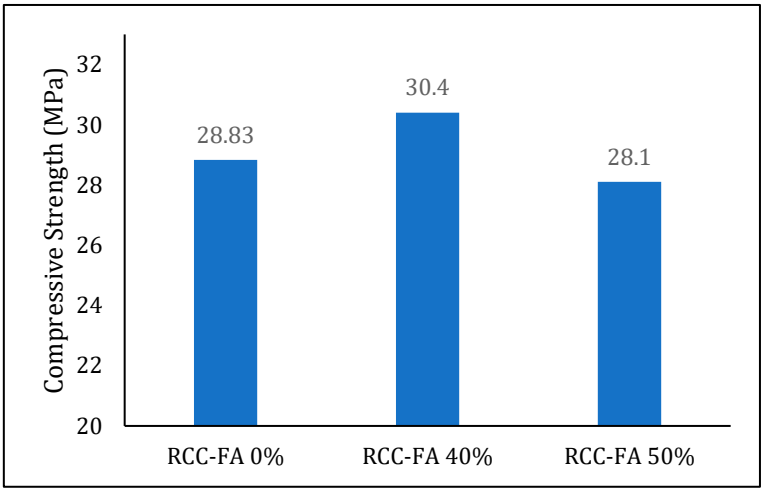

Figure 5. Compressive strength test graph of roller compacted concrete.

Furthermore, there was a percentage decrease in compressive strength of 2.70% with a 50% fly ash substitution. This occurred due to the reaction of cement with water producing CSH (calcium silicate hydrate) and a by-product in the form of Ca $(OH)_2$.

Figure 6 shows the comparison graph of compressive strength test results from research by Mardani-Aghabaglou [9] and CD Atis [27]. This study agrees with the study conducted by Agustiany [27] where Ca $(OH)_2$ the by-product of cement and water is produced after fly ash reacts and produces new CSH at later ages. This means that the pozzolan produced by fly ash is not optimal at the early ages of 7–28 days.

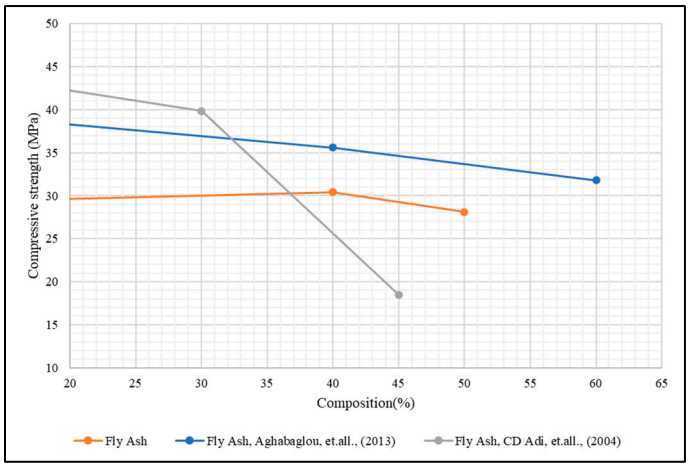

Figure 6. Comparison Graph of Compressive Strength Test Results from Research by Aghabaglou, et al. [9] and Atis et.al. [27].

Research conducted by Mardani-Aghabaglou [9] on the mechanical properties of RCC in fly ash variations of 40% and 60% obtained compressive strength values of 35.6 MPa and 31.8 MPa, respectively, after 28 days. Similarly, research conducted by CD Atis on the use of fly ash in an RCC mixture with fly ash variations of 30% and 45% obtained compressive strength values of 39.83 MPa and 18.48 MPa, respectively [26]. All the above studies agree with the research results, which show that compressive strength decreased with the increase in fly ash content by a certain percentage.

This study's results differ from the results in the studies mentioned above. This difference in the compressive strength test results is due to the mixture calculation difference used in each study. Mardani used a mixture calculation from ACI 207.5R.89 with 250 kg/m^3 cement in fly ash variations of 20%, 40%, and 60%, while this study used a reference mixture

calculation from Brownville, TX, USA [16] with 300 kg/m^3 cement in fly ash variations of 0%, 40%, and 50%. These factors, along with water content, can affect the mechanical properties of concrete.

3.3. Split Tensile Strength Test

This study conducted a splitting tensile strength test of concrete to evaluate the shear strength of concrete. This was carried out by giving tensile stress to the concrete indirectly with ordinary water immersion expecting a splitting tensile strength of 2.80–4.10 MPa at a concrete age of 28 days. By utilizing the Universal Testing Machine (UTM) to test the strength of concrete, Figure 7 shows the results of the splitting tensile strength test graph of RCC.

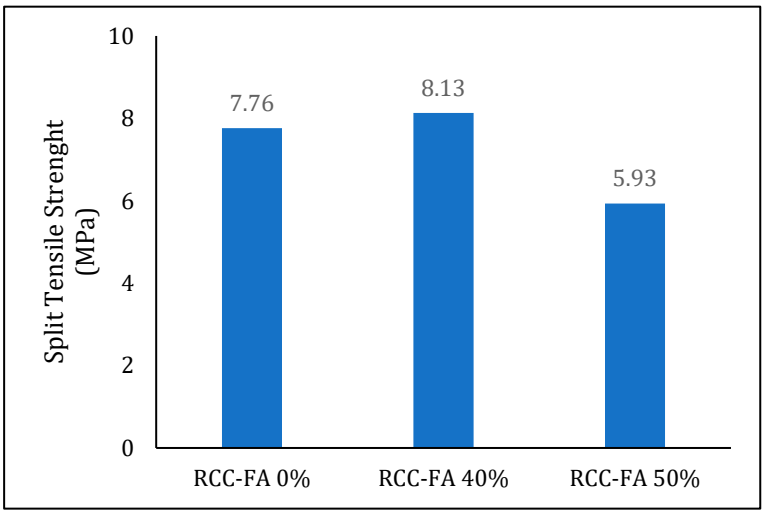

Figure 7. Split tensile strength test graph of roller compacted concrete.

From Figure 7 above, the results show a splitting tensile strength value of 7.60 MPa at 0% fly ash content after 28 days. At 40%, the splitting tensile strength is 8.13 MPa, whereas a splitting tensile strength value of 6.90 MPa is obtained at 50%. The ideal splitting tensile strength is obtained at a 40% variation in fly ash and becomes lower, followed by adding fly ash content, and it was also found in the previous research that fly ash as a cement partial replacement meets the required splitting tensile strength of 2.8 to 4.1 MPa after 28 days, according to ACI 325.10R [15,28].

The tensile strength value increased by 4.76% at 40% fly ash replacement, showing that fly ash can increase concrete's splitting tensile strength value. This occurs because of the hydration reaction between the water, cement, and fly ash binders.

However, increasing the percentage of fly ash in the concrete mixture produces a less-than-optimal splitting tensile strength value because forming bonds in concrete will be slower.

A study showed that the initial bond formation time will be slower with the increase in fly ash content. This is because new reactions from the main compounds of fly ash, such as silica and alumina prolong the hydration process resulting in a longer setting time [29].

Figure 8 shows a comparison of concrete splitting tensile strength values from different research. Research conducted by Mardani-Aghabaglou on the mechanical properties of RCC with variations in fly ash of 40%, and 60% obtained a concrete splitting tensile value of 3.81 MPa and 3.54 MPa, respectively, after 28 days. Similarly, research conducted by CD Atis on the use of fly ash in a mixture of RCC with fly ash percentages of 30%, and 45% obtained splitting tensile strength of 2.77 MPa and 1.82 MPa, respectively.

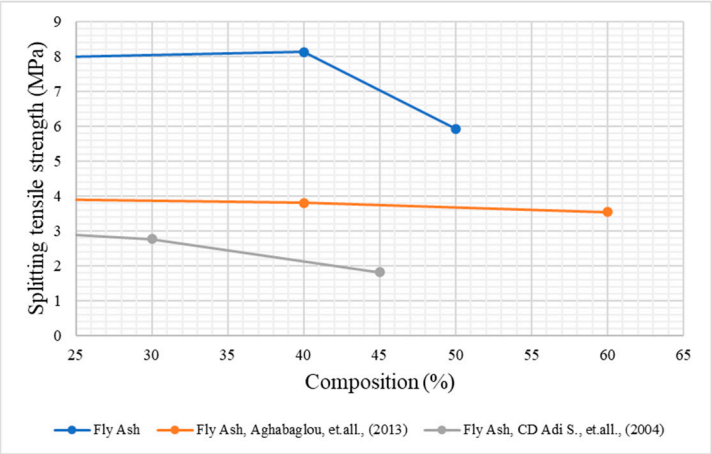

Figure 8. Comparison Graph of Concrete Splitting Tensile Strength Test Results from Research by Aghabaglou, et al. [9] and Atis et.al. [27].

This study used fly ash percentages of 0%, 40%, and 50%, thereby obtaining concrete splitting tensile strength values of 7.76 MPa, 38.13 MPa, and 5.93 MPa, respectively, after 28 days.

4. Conclusions

This study used an experimental approach to provide answers to researchers in the RCC field in Indonesia by conducting several tests such as vebe time tests, compressive strength, and splitting tensile strength of concrete. The following conclusions were made based on the above specimen:

Vebe time test of fresh concrete on RCC shows that fly ash waste can be used as a partial substitute for cement. This is seen from the vebe time at a variation of 50% fly ash not less than the optimal vebe time to increase workability.

The compressive strength and splitting tensile strength tests show that using a 40% fly ash replacement in RCC has a higher strength value than the control RCC. Compressive strength and splitting tensile strength after 28 days are 30.4 MPa and 8.13 MPa, respectively, at an optimum fly ash variation of 40%. A higher strength is needed for road pavement with higher load traffic [30].

This study shows that the 40% fly ash variation has a positive impact and is superior to other variations in all tests. It can be concluded that the RCC in this study meets the ACI.325.10R standard requirement, and is thereby eligible and accepted for road paving construction.

Author Contributions: M.S. conceptualized the research program and reviewed and edited the final publication; G.A.A.I. was responsible for lab investigation, data curation, and original draft preparation; Y.N. supervised the project; N.K.H. reviewed the data acquisition. All authors have read and agreed to the published version of the manuscript.

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References

1. Subakti, A. *Teknologi Beton Dalam Praktek*; Jurusan Teknik Sipil FTSP, Institut Teknologi: Surabaya, Indonesia, 1995.
2. Marga, D.J.B. Manual Perkerasan Jalan, Kementrian Pekerjaan Umum dan Perumahan Rakyat Direktorat Jendral Bina Marga. 2017, pp. 1–235. Available online: https://binamarga.pu.go.id/v3/uploads/files/112/manual-desain-perkerasan-jalan.pdf (accessed on 8 November 2024).
3. Khayat, K.H.; Libre, N.A. Roller Compacted Concrete: Field Evaluation and Mixture Optimization. 2014. Available online: https://www.researchgate.net/publication/264734306 (accessed on 8 October 2024).
4. Srinivas, K.; Vijaya, S.K.; Jagadeeswari, K. Concrete with ceramic and granite waste as coarse aggregate. *Mater. Today Proc.* **2020**, *37 Pt 2*, 2089–2092. [CrossRef]
5. Global Warming Impact on the Cement and Aggregates Industries Davidovits-1 [Internet]. Available online: www.geopolymer.org (accessed on 10 November 2024).
6. *SNI 03-2491-2002*; Metode Pengujian Kuat Tarik Belah Beton. Badan Standar Nasional: Jakarta, Indonesia, 2002; p. 14.
7. Pavan, S.; Rao, S.K. Effect of Fly ash on Strength Characteristics of Roller Compacted Concrete Pavement. *IOSR J. Mech. Civ. Eng. (IOSR-JMCE)* **2014**, *11*, 4–8. Available online: www.iosrjournals.org (accessed on 20 October 2024). [CrossRef]
8. Desliono, W.; Parung, H.; Rapang Tonapa, S. Pemanfaatan FIy Ash Sebagai Substitusi Semen Dan Batu Gamping Sebagai Agregat Pada Beton. *Paulus Civ. Eng. J.* **2021**, *3*, 209–216. [CrossRef]
9. Mardani-Aghabaglou, A.; Ramyar, K. Mechanical properties of high-volume fly ash roller compacted concrete designed by maximum density method. *Constr. Build. Mater.* **2013**, *38*, 356–364. [CrossRef]
10. Lam, M.N.T.; Le, D.H.; Jaritngam, S. Compressive strength and durability properties of roller-compacted concrete pavement containing electric arc furnace slag aggregate and fly ash. *Constr. Build. Mater.* **2018**, *191*, 912–922. [CrossRef]
11. Harrington, D.; Abdo, F.; Ceylan, H.; Adaska, W.; Hazaree, C.; Bektas, F. *Guide for Roller-Compacted Concrete Pavements*; National Concrete Pavement Technology Center: Ames, IA, USA, 2010.
12. *ACI 207.5R-11*; Roller Compacted Concrete. American Concrete Institute (ACI): Farmington Hills, MI, USA, 2011.
13. Chhorn, C.; Kim, Y.K.; Hong, S.J.; Park, J.Y.; Lee, S.W. A study on performance of roller-compacted concrete pavement in accelerated pavement tests. *J. Test. Eval.* **2018**, *48*, 2611–2623. [CrossRef]
14. Tangaramvong, S.; Nuaklong, P.; Khine, M.T.; Jongvivatsakul, P. The influences of granite industry waste on concrete properties with different strength grades. *Case Stud. Constr. Mater.* **2021**, *15*, e00669. [CrossRef]
15. *ACI 325-10*; State of Art Report. On Roller Compacted Concrete Pavements. American Concrete Institute (ACI): Farmington Hills, MI, USA, 2010.
16. *ASTM C1176/C1176M-20*; Standard Practice for Making Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Table. ASTM: West Conshohocken, PA, USA, 2020.
17. *ASTM C1435-99*; Standard Practice for Molding Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Hammer. ASTMInt'l: West Conshohocken, PA, USA, 2009.
18. Selvam, M.; Singh, S. Tailoring of Compaction Parameters of the Vibratory Table and Vibratory Hammer for Roller Compacted Concrete Pavements to Resemble Field Properties. *Transp. Res. Rec.* **2024**, *2678*, 242–258. [CrossRef]
19. Şengün, E.; Alam, B.; Shabani, R.; Yaman, I.O. The effects of compaction methods and mix parameters on the properties of roller compacted concrete mixtures. *Constr. Build. Mater.* **2019**, *228*, 116807. [CrossRef]
20. *BS EN 12350-3:2009*; Testing Fresh Concrete Part 3: Vebe Test. British Standard: London, UK, 2009.
21. Setiawati, M. Fly Ash Sebagai Bahan Pengganti Semen Pada Beton. In Proceedings of the Seminar Nasional Sains Dan Teknologi, Central Jakarta, Indonesia, 17 October 2018; pp. 1–8.
22. *ACI 325.10R-95*; Report on Roller-Compacted Concrete. American Concrre Institute (ACI): Farmington Hills, MI, USA, 1995.
23. Sengun, E.; Shabani, R.; Alam, B.; Aykutlu, M.; Yaman, I. Comparison of Several Laboratory Compaction Practices Applied on Roller Compacted Concrete Pavements. 2018, pp. 12–14. Available online: https://www.researchgate.net/publication/339850771 (accessed on 28 October 2024).
24. *SNI 1974–2011*; Cara Uji Kuat Tekan Beton Dengan Benda Uji Silinder. Badan Standardisasi Nasional: Jakarta, Indonesia, 2011; p. 20.

25. Rahmani, E.; Sharbatdar, M.K.; HABeygi, M. A comprehensive investigation into the effect of water to cement ratios and cement contents on the physical and mechanical properties of Roller Compacted Concrete Pavement (RCCP). *Constr. Build. Mater.* **2020**, *253*, 119177. [CrossRef]
26. Chhorn, C.; Hong, S.J.; Lee, S.W. Relationship between compressive and tensile strengths of roller-compacted concrete. *J. Traffic Transp. Eng. (Engl. Ed.)* **2018**, *5*, 215–223. [CrossRef]
27. Atiş, C.D.; Sevim, U.K.; Özcan, F.; Bilim, C.; Karahan, O.K.A.N.; Tanrikulu, A.H.; Ekşi, A. Strength properties of roller compacted concrete containing a non-standard high calcium fly ash. *Mater. Lett.* **2004**, *58*, 1446–1450. [CrossRef]
28. Agustiany, A.A.; Nanik, S.B. *Pembuatan Beton Mutu Tinggi Dengan Variasi Bahan Tambah Fly Ash, Silica Fume dan Superplasticizer*; Universitas Islam Indonesia: Yogyakarta, Indonesia, 1998.
29. Tabaiyan, M.F.Y.; Prasetyaningtiyas, G.A. Pengaruh Penambahan Zat Aditifgrolen HP10+ dan Additon HE Water Reducing Retarding Admixture Superplasticizer terhadap Kuat Tekan Beton, Prosiding Seminar Nasional Teknik Sipil UMS 2023, Universitas Muhammadiyah Surakarta. 2023. Available online: https://proceedings.ums.ac.id/sipil/article/view/2688 (accessed on 15 October 2024).
30. Puro, S.; Atmiwyastuti, N.; Restina, N. Kritik dan Pemecahan Penggunaan Konstruksi Beton cor pada Rekayasa Jalan Dalam Upaya Membangun Konstruksi Jalan Yang Berkelanjutan. *Media Tek. Sipil* **2015**, *12*. [CrossRef]

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