Kaunas University of Technology

Faculty of Civil Engineering and Architecture

The Investigation of Roller Compacted Concrete with Fly Ash Using Gyratory Compactor

Master’s Research Project

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Kaunas, 2024

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Structural And Building Products Engineering (6211EX008)

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Task of the Master's Degree Final Project

Study programme: STRUCTURAL AND BUILDINGS PRODUCTS ENGINEERING

Topic of the project (English):
THE INVESTIGATION OF ROLLER COMPACTED CONCRETE WITH FLY ASH USING GYRATORY COMPACTOR

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VOLUOJAMO BETONO SU PELENAIS TYRIMAI NAUDOJANT GIRATORINĮ TANKINIMĄ

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DURABLE AND SUSTAINABLE CONCRETE

Parts of the degree project:	**Be accomplished:**
Introduction	**x**
Literature review	**x**
Research methodology	**x**
Experimental research	**x**
Analytical research	☐
Numerical research	☐
Economical part	☐
Conclusions	**x**

Other information (if needed):

Supervisor: (contribution__ %)	Doc. dr. Audrius Grinys *position, name, surname*	*Confirmed electronically* *signature*
Student:	Jishnu Vijayan *name, surname*	*Confirmed electronically* *signature*

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Kaunas, 2024. 57 p.

Summary

The research project aimed to identify the optimal cement usage levels that maintain or enhance concrete strength compared to standard concrete while examining the impact of using fly ash as a binder on concrete properties, targeting a minimum C30/37 class of concrete. This investigation comprehensively assessed strength characteristics, resistance to freezing and thawing, water absorption, and porosity of the concrete.

This extensive research examines deeply into the effectiveness of concrete by analysing its strength characteristics, resistance to freezing and thawing, water absorption behaviours when submerged, and relevant porosity values. This study highlights the importance of cement and fly ash proportions in determining the final concrete's mechanical properties, longevity, and sustainability.

The numerous benefits of Roller Compacted Concrete (RCC), especially its extensive used in the construction of concrete pavements, made it a crucial area of study. In addition to physical characteristics like density and porosity, this research paper discusses the complex interactions between mechanical properties like compressive strength, split tensile strength, and flexural strength and durability indicators like the freeze-thaw (CDF) test and resistance to de-icing solutions. In order to strengthen the durability quotient of RCC, the paper cleverly ties these parameters to the finer points of mix design, highlighting their mutually beneficial relationship.

The study proposes a mix ratio of 310 kg/m^3 for cement and a 20% fly ash substitution, which is the ideal combination for durability enhancement. A careful composition of fine aggregate (45% of size 0 to 4 mm), coarse aggregate (15% of size 2 to 8 mm), and additional coarse aggregate (40% of size 8 to 16 mm) is embraced by this suggested mix design. Furthermore, a water-to-cement ratio of 0.425 is suggested, explaining its critical function in enhancing the endurance and strength limits of RCC constructions.

These results, taken together, highlight the critical importance of careful mix design in fulfilling project-specific requirements and guaranteeing the durability, sustainability, and reliability of RCC structures in a variety of construction applications. They draw attention to the necessity of carefully calibrating material composition in order to surpass the high standards of strength and durability anticipated in modern construction.

Vijayan, Jishnu. Voluojamo betono su pelenais tyrimai, naudojant giratorinį tankinimą. Magistro baigiamasis projektas / vadovas doc. dr. Audrius Grinys; Kauno technologijos universitetas, Statybos ir architektūros fakultetas.

Studijų kryptis (studijų sritis): inžinerijos mokslai, statybos inžinerija (E05).

Reikšminiai žodžiai: Volu sutankintas betonas, lakštas, sutankintuvas, tankis, piršto nuosmukio bandymas, gniuždymo stipris, skilimo tempimo stipris ir teorinis lenkimo stiprumas, vandens sugėrimas, užšalimas ir atšildymas.

Kaunas, 2024. 57 p.

Santrauka

Tyrimo projektu buvo siekiama nustatyti optimalius cemento panaudojimo lygius, išlaikančius arba padidinančius betono stiprumą, palyginti su standartiniu betonu, nagrinėjant lakiųjų pelenų, kaip rišiklio, poveikį betono savybėms, taikant minimalią C30/37 betono klasę. Šio tyrimo metu buvo visapusiškai įvertintos betono stiprumo charakteristikos, atsparumas užšalimui ir atitirpimui, vandens įgeriamumas ir betono poringumas.

Šiame išsamiame tyrime išsamiai nagrinėjamas betono efektyvumas, analizuojant jo stiprumo charakteristikas, atsparumą užšalimui ir atitirpimui, vandens sugėrimą panardinant ir atitinkamas poringumo vertes. Šis tyrimas pabrėžia cemento ir lakiųjų pelenų proporcijų svarbą nustatant galutinio betono mechanines savybes, ilgaamžiškumą ir tvarumą.

Dėl daugybės ritininio suspausto betono (RCC) pranašumų, ypač didelio jo naudojimo betoninių dangų statyboje, jis tampa itin svarbia studijų sritimi. Be fizinių savybių, tokių kaip tankis ir poringumas, šiame moksliniame darbe aptariamos sudėtingos sąveikos tarp mechaninių savybių, tokių kaip gniuždymo stipris, skilimo tempiamasis stiprumas ir lenkimo stiprumo bei ilgaamžiškumo rodikliai, tokie kaip užšalimo-atšildymo (CDF) bandymas ir atsparumas ledo tirpalams. . Siekiant sustiprinti RCC patvarumo koeficientą, popierius sumaniai susieja šiuos parametrus su smulkesniais mišinio dizaino taškais, pabrėždamas jų abipusį naudingą ryšį.

Tyrime siūlomas 310 kg/m^3 cemento ir 20 % lakiųjų pelenų pakeitimo santykis, kuris yra idealus derinys ilgaamžiškumui padidinti. Šis siūlomas mišinys apima kruopščią smulkaus užpildo (45% dydžio nuo 0 iki 4 mm), stambaus užpildo (15% nuo 2 iki 8 mm dydžio) ir papildomo stambaus užpildo (40% nuo 8 iki 16 mm dydžio) sudėtį. dizainas. Be to, siūlomas vandens ir cemento santykis 0,425, paaiškinantis jo esminę funkciją didinant RCC konstrukcijų patvarumo ir stiprumo ribas.

Šie rezultatai kartu pabrėžia kruopštaus mišinio projektavimo svarbą įgyvendinant specifinius projekto reikalavimus ir garantuojant RCC konstrukcijų ilgaamžiškumą, tvarumą ir patikimumą įvairiose statybos srityse. Jie atkreipia dėmesį į būtinybę kruopščiai kalibruoti medžiagų sudėtį, kad būtų viršyti aukšti stiprumo ir ilgaamžiškumo standartai, kurių tikimasi šiuolaikinėje statyboje.

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Introduction

RCC, or roller compacted concrete, is a low workability, zero slump concrete. When it is still fresh, it is sufficiently dry to be compacted with road construction equipment under compressive and vibration loads. RCC had drawn more attention in the last few years because of its low cost, quick construction time, and capacity to attain greater strength earlier than traditional concrete pavement. The main advantage of this was that it made it possible for the developed road to be immediately opened to traffic [1] [2].

Due to the substantial carbon dioxide emissions from the cement industry, 927 kg of CO2 are released during the production of 1000 kg of cement, which raises environmental concerns. Fly ash is an environmentally friendly alternative to cement in the production of concrete, resulting in a significant reduction of CO2 emissions of 150 kg CO2 produced per 1000 kg [3]. To determine whether using fly ash in construction projects is cost-effective, a thorough analysis and financial comparison were conducted. The findings showed that using fly ash can result in significant cost savings, which mades it a financially beneficial option for environmentally friendly [4].

RCC is made of cement, water, and aggregates with a continuous grading, just like regular concrete. However, the aggregates constitute more than 85% of the volume of RCC, with fine-grained aggregates making up the majority of the material [5]. The RCC guide gives that the compressive and split tensile strength of RCC range is 28 to 41 MPa and 3.5–7 MPa at 28-days [6], respectively [7]. The main factor affecting pavement structures in European nations is the freezing-thawing effect, which shortens the lifespan of concrete [8].

The aim of this research project is to determine the lowest cement usage levels at which the strength properties of the concrete will either remain the same or improve in comparison to standard concrete, while also analysing the effects of using fly ash as a binder material on the mechanical, physical, and durability properties of the concrete to obtain a minimum C30/37 class of concrete. This study looked into the concrete's strength characteristics, resistance to freezing and thawing, water absorption through immersion, and porosity parameters.

RCC had many benefits and is frequently used in the construction of pavements. This paper clarifies the complex relationship that exists between the mechanical properties like compressive strength, split tensile strength and flexural strength, physical properties like density, porosity and durability properties like de-icing solution and freeze-thaw (CDF) test of RCC and the parameters of mix design. In order to increase durability, it suggests an ideal mix proportion includes a cement content of 310 Kg/m^3 with a 20% partial replacement fly ash. The suggested mix design encompasses fine aggregate of size 0 to 4 mm (45%), coarse aggregate of size 2 to 8 mm (15%), and coarse aggregate of size 8 to 16 mm (40%), along with a water-cement ratio of 0.425. These results highlight the need of careful mix design to satisfy project-specific specifications and guarantee the durability, sustainability and strength of RCC structures in a variety of construction applications.

1. Literature Review

The RCC mix's strength was reduced and water absorption was increased as a result of the partialy replace of cement with fly ash. In contrast, replacing aggregate with fly ash reduced the water/cement ratio, which resulted in less water absorption and more strength. The increase in binder concentration from 250 kg/m^3 to 390 kg/m^3 in particular had a substantial impact on the mixes' strength [9].

According to the findings, the RCCP had the highest dry density and had a moisture content of 5.7%. However, 5% moisture content yielded the highest mechanical properties, porosity is low, and water absorption values are also low. . This implies that a workable, strong, and long-lasting RCC can be produced with a moisture content that is lesser than the ideal moisture content that corresponds to the highest possible dry density [10].

After that, the review concentrates on the RCCP's numerous mechanical characteristics, such as its elastic modulus and compressive, flexural, and tensile strengths. Additionally discussed are the effects of fatigue, creep, volume change, bond strength, thermal characteristics, permeability, and durability (including resistance to abrasion/erosion, freezing and thawing, and water absorption). In conclusion, this review of the literature gives a broad overview of the mechanical, durable, and other pertinent features of RCCP [11].

In terms of producing desired strengths and compaction ratios within an acceptable Ve-be consistency test, the Superpave gyratory compactor (SGC), followed by the vibrating hammer, is found to be the most suitable laboratory compaction method. In conclusion, this work examines how laboratory compaction techniques affect the mechanical and physical characteristics of RCC. The preferred approach for accurately simulating field compaction conditions and obtaining trustworthy strength findings is the Superpave gyratory compactor (SGC) [12].

The findings show that the compressive strength, the flexural strength of RCC is within the range of values expected by traditional concrete equations. However, given the same compressive strength, RCC's splitting tensile strength is considerably lower than the traditional concrete. The indirect tensile strengths of RCC and traditional concrete are compared in this work, and regression equations are established to calculate tensile strengths based on the compressive strength of RCC. The results indicate that while the splitting tensile strength of RCC is considerably lower for a given compressive strength, the flexural strength of RCC aligns with standard concrete equations [13].

According to the findings, full graded RCC is suitable with a water-binder ratio between 0.45 to 0.50, water consumption of 70 kg/m^3, sand ratio of 30%, and stone combination of 20:30:30:20. The compressive strength of the full-graded RCC samples is 10% more than that of the tiny wet-screened samples, while the tensile strength had significantly decreased. In this study, the impact of coarse aggregate size on RCC characteristics is investigated. In comparison to wet-screened tiny samples, full-graded RCC with precise mix proportions exhibits increased compressive strength, deformation control, volume stability, and frost resistance. The results point to full-graded RCC's ability to improve concrete properties, cut down on material use, and improve technical and financial aspects [14].

In this work, high volume fly ash RCC mixtures made in the lab and in the field are compared in terms of interlayer cold joint formation, treatment approaches, strength, and permeability. There are discrepancies between laboratory and field mixtures as a result of the fact that the soil compaction technique frequently utilized in RCC pavement design does not accurately reflect field compaction performance. The combination with partial fly ash replacement in the aggregate is chosen for the construction of an RCC road based on the laboratory and early field study results. The road is a single layer that had a compacted thickness of roughly 0.20 m, a width of 7 m, and a length of 100 m. His work emphadizes the variations in interlayer cold joint formation, strength, and permeability between laboratory and field RCC mixes. It showing difficulties with the installation of RCC in many layers and proposes that differences in compaction, curing, and cold joint properties may cause laboratory specimens to be stronger than field specimens [15].

The slag materials are tested in a laboratory physically and chemically for determine the engineering qualities. 12 mix designs are created using graded slag aggregates, cementitious materials, water, and air-entrained admixtures based on the test findings to produce the best possible mix. The ideal mixture had 13% cementitious ingredients, including 20% of fly ash, 30% of slag cement, and 50% Portland cement. This study assesses the effectiveness of slag materials in RCC and shows how they can be successfully recycled for both financial and environmental gains. The study demonstrates the potential financial savings and environmental benefits of using steel slag materials, which were previously thought to be unsuitable, in construction projects [16].

Fly ash replaces a portion of the aggregate equal to 20%, 40%, and 60% of the cement in one series and 20%, 40%, and 60% (by weight) of the aggregate in the other. There are a total of 28 combinations created with various water/binder ratios is 0.30, 0.35, 0.4, and 0.45. For further analysis, seven mixes with the ideal water content are chosen. This study shows that replacing aggregate with fly ash increases strength values compared to the control combination while replacing cement with fly ash decreases strength values in RCC mixtures. These results demonstrate the impact of fly ash content and how it affects the mechanical characteristics of RCC [17].

Research on the RCC having high volume of fly ash is described in this study. The mixtures were created by adding large amounts of fly ash, range from 40% to 85% by total cementitious material, and cement at concentrations of 50-260 kg/m^3 and permeability, absorption, and chloride diffusion of the concretes were examined. The investigation revealed that the permeability, absorption, and chloride diffusivity values of RCCs with moderate cement and moderate fly ash levels were reduced [18].

The investigation found that the middle gradation (GM) mixture had compressive strengths that were 6% and 11% higher than those of the lower and upper gradation mixes. Similar to this, the middle gradation mix's split tensile strength increased by 12% in comparison to the lower and upper gradation mixes.vAccording to these findings, the strength characteristics of roller-compacted concrete can be greatly influenced by the choice of aggregate gradation and cement quantity. The study emphadizes how crucial parameter optimization is to achieving the necessary strength properties in RCC. The study offers insightful information regarding the connection between aggregate gradation, cement percentage, and the resulting compressive and split tensile strength of the roller compacted concrete. The design and construction of RCC can be guided by this knowledge in order to satisfy certain strength requirements in a variety of application [19].

The research highlights the difficulties in creating representative lab specimens for Roller-Compacted Concrete (RCC) because of the material's dryness and the significant compactive effort needed to achieve field densities. It was discovered that the gyratory compactor, which is usually used for hotmix asphalt, can be used to produce RCC specimens with mechanical characteristics that match field performance. These specimens had low variability, a constant density, and high strength. Because of its dependability and consistency with field data, the results indicate that the gyratory compactor presents a competitive alternative to traditional techniques (like the modified Vebe apparatus, vibrating table, or vibrating hammer). Furthermore, the study emphasizes how specimen aspect ratio and density affect compressive and splitting tensile strength, showing that the quantity of gyrations can faithfully reproduce the intended field density values. About 60 gyrations were able to accurately replicate reality for the industrial pavements under investigation, highlighting the gyratory compactor's usage in RCC specimen preparation for accurate representation of real-world performance [20].

The study confirms that using stone grain and naturally occurring pozzolan in roller-compacted concrete (RCC) gravity dams is a promising practical and efficient solution. The physical and chemical characteristics of five distinct supplemental materials, such as different fly ashes and natural pozzolans, were carefully evaluated. The effectiveness of these materials in reducing alkali silica the interaction was assessed, which is an important factor in RCC construction. The study used Jordanian Portland Cement to establish correlations between the mechanical properties of the suggested mixes and a control mix. The results demonstrated that Natural Pozzolana and rock flour performed similarly to fly ash and other pozzolanic materials. Interestingly, these substitute materials performed exceptionally well, indicating that they can be used successfully in RCC construction. The results of this research investigation support the use of natural pozzolan and rock flour as feasible cement substitutes in RCC gravity dams, while also validating their potential. Their ability to control the response of alkali silica and their suitable performance support as useful alternatives for improving the long-term viability and productivity of RCC construction methods [21].

The results strongly suggest that RCC mixes intended for low-cement bike path pavements should have a cement content greater than 250 kg/m³. In addition, a recommended water content of more than 120 kg/m³ was found for binder materials more than 250 kg/m³ in order to guarantee the workability. Using a compaction method that achieves a ratio exceeding 93% is essential to the effective construction of the RCC pavement. The aforementioned recommendation highlights the significance of rigorous compaction techniques in ensuring the intended functionality and longevity of low cement-based RCC in the context of automobile road construction. The study's conclusions offer insightful advice for improving RCC mixes and compaction techniques, which will improve the mechanical performance of bike path pavements [22].

The integration of research endeavors in this manuscript represents a significant advancement in the establishment of roller-compacted concrete (RCC) as an eco-friendly and sustainable roadway building material. Recycled road wastes, utilized concrete aggregate, slag from electric arc furnaces, waste from cross-linked polyethylene, silica fume, bagasse ash, ground granulated blast furnace slag, jarosite, crumb rubber, rice husk ash, fly ash, sugarcane ash, coal waste ash, and coal waste powder were among the materials used in the investigation. The extensive investigation examined the effects of these various materials on the mechanical, long-term, and novel properties of RCC. Positively, a number of materials showed good results when partially replaced or combined with the components of roller-compacted concrete. These encouraging outcomes highlight the cost-saving benefits of construction methods in addition to the potential for environmental benefits like lowering carbon emissions. Using these different types of materials offers a promising way to promote sustainable development in road building. RCC has the potential to provide both economic benefits and improved environmental performance by utilizing these substitute materials. Accepting these discoveries has the potential to transform pavement building and open the door to a more economical, environmentally friendly method of infrastructure development that also happens to be environmentally friendly as well [23].

This research examines the effects of two RCC pavements with cement contents of 12% (269 kg/m^3) and 15% (325 kg/m^3) on hardened characteristics, durability, ultrasonic pulse velocity (UPV), and thermal conductivity at different levels of superplasticizer (SP) usage (0.25% and 0.50%). The findings indicate that when using 0.50% SP in RCC pavement with 12% and 15% cement the Vebe time decreased by 22% and 27% respectively. Furthermore increasing the cement content from 12% to 15% resulted in a 18% decrease in Vebe time. With the application of 0.50% SP the compressive strength at the age of 28 days increased by 9% for RCC pavements with a cement content of 12%. By about14 % for those with a cement content of15%. Additionally employing0.50 SP led to a reduction in porosity levels for RCC pavement. Around8 % for pavements with a cement content of12% and about4 % for those witha cementcontentof15%. The outcomes also demonstrated that using0.5 % SP increased conductivity in RCC pavements containingcement contents of12 %and15 %, and7% respectively.In general the test results, for UPV and Field Emission Scanning Electron Microscope (FESEM) indicated that incorporating SP in RCC pavement can result in a structure [24].

The findings of the study demonstrate that it is possible to incorporate recycled aggregates, into roller compacted concrete (RCC) without changing its physical properties. The experimental program examined the impact of ratios of recycled replacements on RCC and drew several important conclusions. The evaluations of properties, such as gas permeability and water absorption revealed an increase as the replacement ratios increased. However despite this increase the mechanical properties remained relatively unaffected. After 28 days all mixtures exhibited strength results; the lowest reduction of 6% was observed when all coarse aggregates were replaced with recycled aggregates. Although tensile and flexural strength experienced decreases at higher replacement ratios (e.g., 100%) these decreases still fell within acceptable limits (around 10%). Importantly the results indicate that incorporating recycled aggregates up to a 50% replacement ratio does not negatively impact the physical properties of RCC. This emphasizes the feasibility of using recycled materials, in RCC production as a approach to reduce waste accumulation caused by urbanization, natural disasters and structural demolition. The findings of the study provide a foundation, for endorsing initiatives in the construction industry promoting the recycling of waste materials and advocating for sustainable approaches, in concrete production [25].

1.1 Roller Compacted Concrete

The RCC is a type of concrete that is roller compacted and practically had zero slump.The created mix is transported by dump trucks or conveyors, distributed on the underlying layer by finishers or specially adapted asphalt pavement, and then compacted by rollers. The use of a roller to compact concrete is the basis for the name [11] [26]. RCC is a particular form of concrete that uses vibrating rollers to compact the concrete to a very tight consistency. It is composed of the same mixture of aggregates, sand, cement, and water as traditional concrete, but with a lower water to cement ratio. RCC is poured and vibrated less than traditional concrete because of its dry and rigid consistency, which enables heavy machines to compact it.

1.1.1. Properties of Roller Compacted Concrete

- High Strength: High compressive strength is exhibited by RCC, which is made possible by the use of effective compaction techniques and low water-cement ratios. It can reach compressive strengths that are comparable to those of regular concrete.

- Durability: Strongly resistant to cracking, abrasion, and freeze-thaw cycles, RCC is extremely long-lasting. Its exceptional long-term performance and good durability are a result of the low water-cement ratio and dense aggregate packing.

- Rapid Construction: Due to its ability to be laid and compacted using large gear, RCC allows for quicker construction than ordinary concrete. Because it does not need formwork or substantial finishing, construction time and costs are reduced.

- Density and Density Stability: RCC had a high density, which boosts its durability and offers resistance to water infiltration. The process of compaction creates a dense and homogenous structure, reducing voids and enhancing permeability resistance.

- Low Maintenance: Because of its strength and resistance to wear and tear, RCC requires little maintenance. When long-term performance and low maintenance requirements are crucial, it is frequently utilized in heavy-duty applications including pavements, industrial floors, and dams.

- Economical: RCC provides economic reductions in terms of building time, materials, and maintenance. It is a cost-effective choice for big projects because of its quick construction and minimal requirement for finishing and formwork.

- Sustainable: RCC is an environmentally favorable choice since it can use industrial byproducts like fly ash or slag as partial replacements for cement. This lessens the use of natural resources and the carbon footprint resulting from the manufacture of concrete.

1.1.2. Applications of Roller Compacted Concrete

- Dam construction
- Road Construction
- Airports
- Rehabilitation of Existing dams
- Storage floors
- Industrial and military facilities

1.2 Experimental Procedure

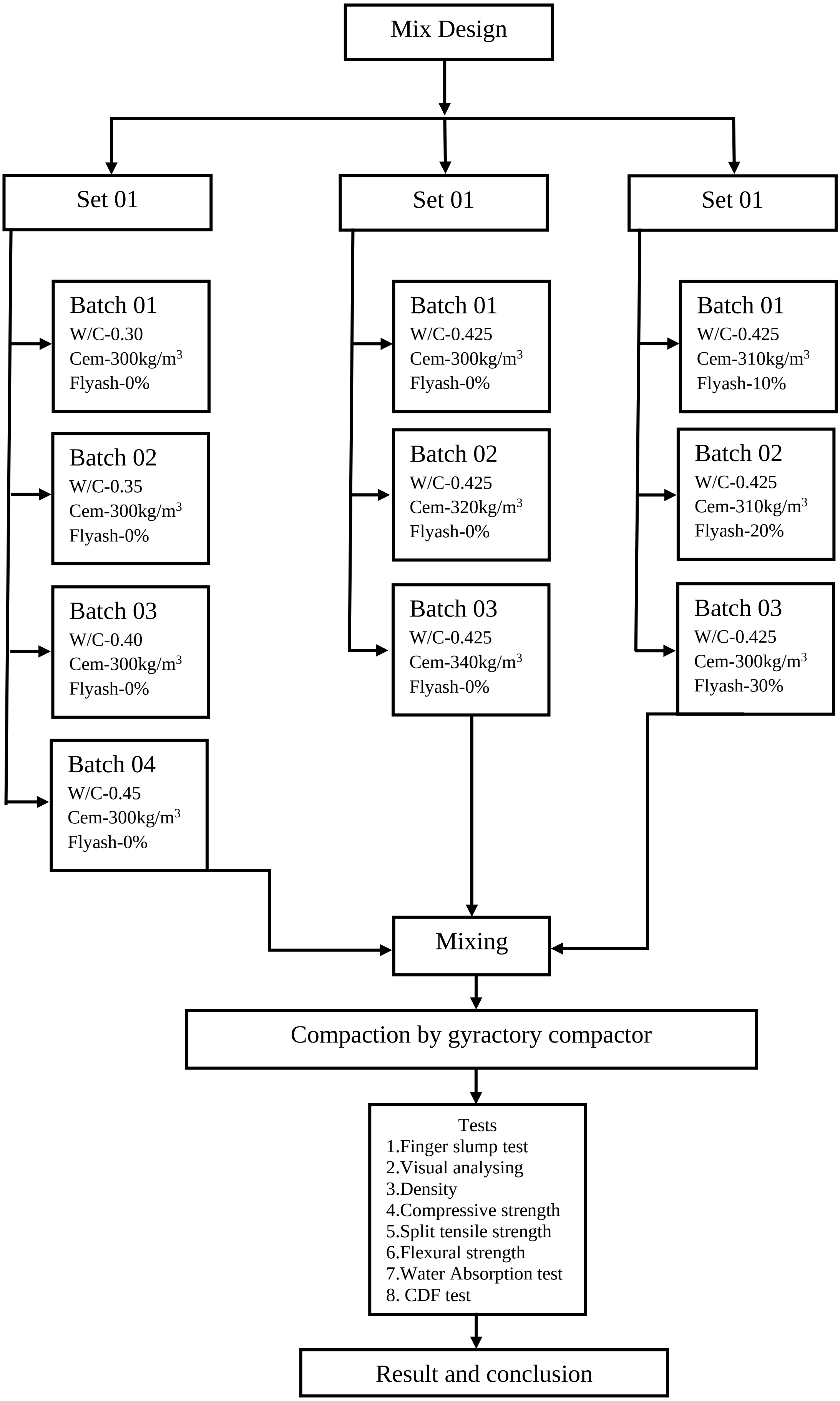


Fig. 1. Experimental procedure

1.3 Materials

1.3.1 Aggregates

The total volume of concrete, aggregate accounts for 70–80%. Aggregate used to be regarded as an inert filler because it lacks the complicated hydration effect found in cement [27]. Researchers have discovered that aggregates in the concrete materials and concrete engineering had a significant and even more impact on a range of important characteristics of concrete, like strength, volume , tensile strength, and durability as development and research in concrete technology had advanced in recent years. [14] The coarse aggregate with the maximum size if 8mm to 16mm and fine aggregate upto 4mm is used in this research. The concrete mixture consisted of 45% sand (fraction 0/4mm) with a particle density of 2650 Kg/m^3 and 15% coarse aggregates (fraction 2/8mm) and 40% (fraction 8/16mm) with a density of 2650 Kg/m^3 as per particles size distribution graph and LST EN 12620. Additionally, fly ash with a minimum of 66% passing through the 0.044 mm (No. 325) sieve was included in the mix [28] (see Fig. 2-3).

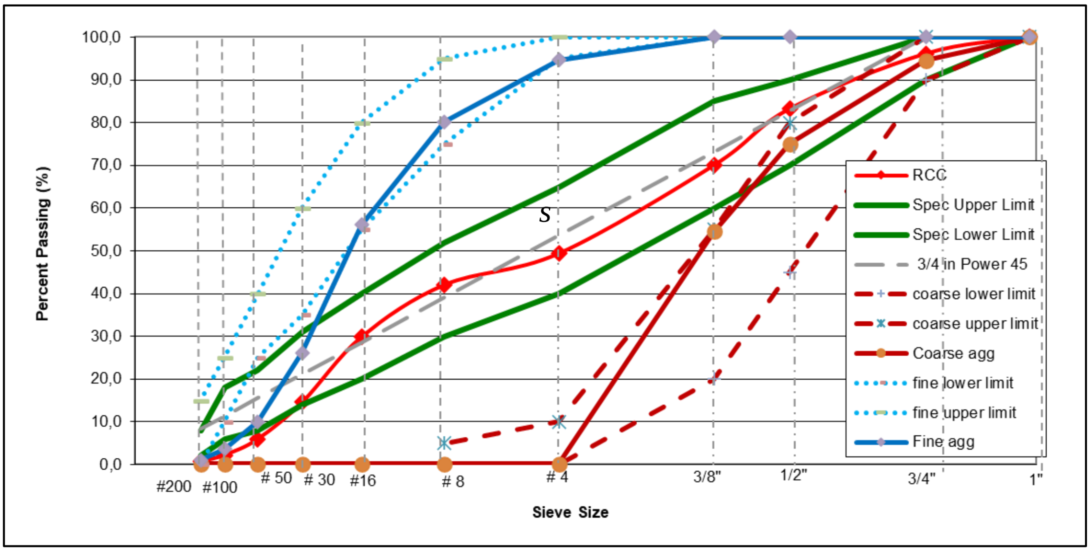


Fig. 2. RCC Aggregate 45 power gradation

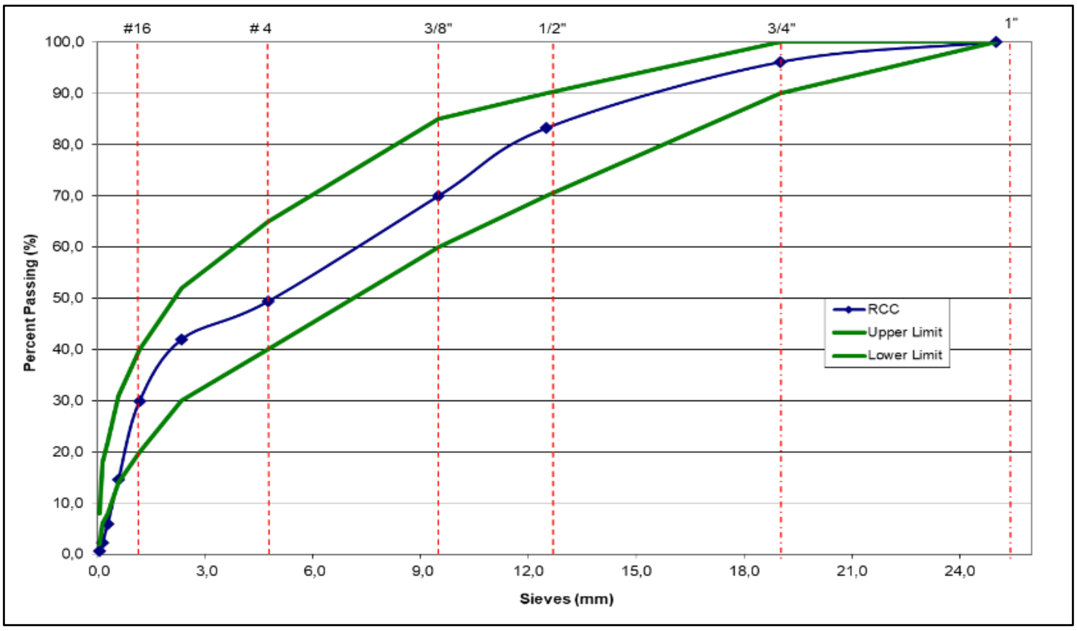


Fig. 3. RCC aggregate gradation chart

1.2.2 Cement

The cement used had a 7-day and 28-day compressive strength of 36 MPa and 48 MPa, respectively, and was plain Portland cement (OPC), Cement had a 3510 cm^2/g specific surface area and a specific gravity of 3.14. In this study, Ordinary Portland cement (CEM I 42.5 N) with a specific gravity of 3.1 according to LST EN 197-1 was used.

1.2.3 Fly ash

A special roller-compacted concrete mixture for pavement contains around 11% by mass of cementitious elements. For ordinary pavement on a highway, the fly ash quantity typically 20–30% of the overall mass of the binder components [29]. Roller's use of Portland cement fly ash is used in some of the compacted concrete, which fly ash contributes the majority of the fine material in the combination. In contrast, a portion of the sand can be substituted with fly ash. Chip in for strength enhancement because to its pozzolanic property. Since the current aggregates do not include enough fine particles, the amount of fly ash can be increased [9] [30].

1.2.4 Water

RCC uses a lot less water for mixing than conventional concrete mixes, however the quality of the water should still be sufficient. [31] Typically, there are 90 to 120 kilos of water per cubic meter. Water to total cementitious ratios, or W/C, for RCC pavement mixtures typically fall between 0.30 and 0.45. W/C ratios in this range provide the most positive effects on the final strength of the RCC. the water source used was groundwater in accordance with LST EN 1008 standards [32].

1.2.5 Admixtures

Admixtures 0.4% of Sika Paver HC44(12%) had the ability to reduce the need for water or moisturizer, and 0.2% of Sika Control-10 LPSA for creating a significant number of reserves micropores in the concrete mix, it improved the hardened concrete's resistance to frost was used in this investigation [33].

1.3 Mix Proportion As Per EN 206

- Exposure Class : XF4
- Maximum W/C : 0.45
- Minimum Cement Content : 340 Kg/m^3
- Minimum Strength : C30/37
- Flyash : <33%

2 Methodolgy

The samples were mixed at the laboratory by following to European standard LST EN 206. The concrete mixtures were prepared using dry materials and in Kaunas University of Technology in building material laboratory located Zyklos rotating pan mixer ZZ 50 HE from Pemat (Germany) (see Fig. 4). The mixing process of concrete mixtures was done according to the 1 table:

Table 1. Mixing sequence and periods

Add materials in sequence	Add materials (seconds from beginning of mixing)	Total mixing time (seconds)
Sand + Coarse aggregate	0	60
Half water dosage	60	120
Pause	120	180
Cement + Admixtures + Rest Water	180	300

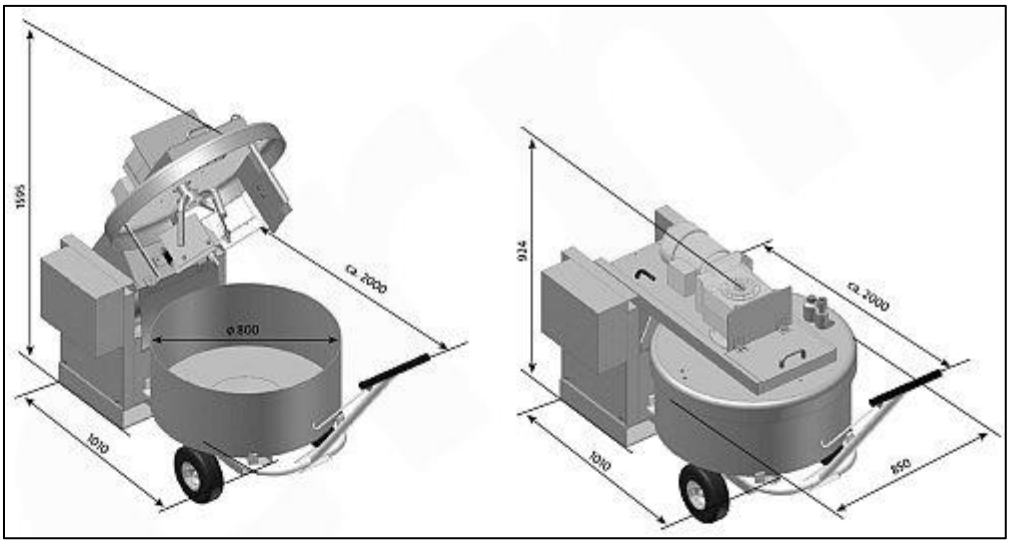


Fig. 4. Simplified scheme of the mixer ZYKLOS ZZ 50 HE

2.1 Experimental Research

2.1.1 The density test of fresh and hardened concrete.

The fresh concrete density was done according European standard LST EN 12350-6 while hardened concrete density was tested according to the requirement of the standard LST EN 12390-7. This standard specifies a method for determining the density of hardened concrete. The mass and volume of the specimen of hardened concrete are determined and the density calculated.

Equipment required for the test. Callipers and rules, capable of determining the dimensions of a specimen to within 0.5 %. Balance, equipped with a stirrup for weighing the specimen in both air and water to an accuracy of 0.1 % of the mass.

Testing procedure:

- Determination of the mass of water-saturated test specimen. Immerse the specimen in water at (20 ± 2) °C until the mass changes by less than 0.2 % in 24 h, wiping the surplus water from the surface before each weighing. Record the value of the saturated mass ms, in kg.
- Determination of the volume of the test specimen, by calculation, using checked, designated dimensions. Calculate the volume of the specimen from measurements made on the specimen following standard EN 12390-1, in m3, rounded to four significant Fig.s.

Calculate the density using the values determined for the mass of specimen and its volume, using the following equation:

$$\rho = \frac{m}{V}, \text{ kg/m}^3 \qquad (1)$$

Where: ρ – the density of the specimen, in kg/m^3; m – the mass of the specimen, in kg; V – the volume of the specimen, in m^3.

2.1.2The compressive strength test of hardened concrete.

The compressive strength test of hardened concrete was conducted according to the requirements of the standard LST EN 12390-3. This standard specifies a method for the determination of the compressive strength of test specimens of hardened concrete. Specimens are loaded to failure in a compression testing machine conforming to LST EN 12390-4. As a compression, the testing machine was used Controls 50-C4042, which was made in Italy (Fig. 5). The maximum load sustained by the specimen is recorded and the compressive strength of the concrete were calculated. The test specimen can be a cube, cylinder or core meeting the requirements of LST EN 12350-1, LST EN 12390-1, LST EN 12390-2, or LST EN 12504-1. Measurement of flatness and perpendicularity is shown in Fig. 6.

Equipment required for the test. Compression testing machine, conforming to LST EN 12390-4. Callipers and rules, capable of determining the dimensions of a specimen to within 0,5 %.

Testing procedure:

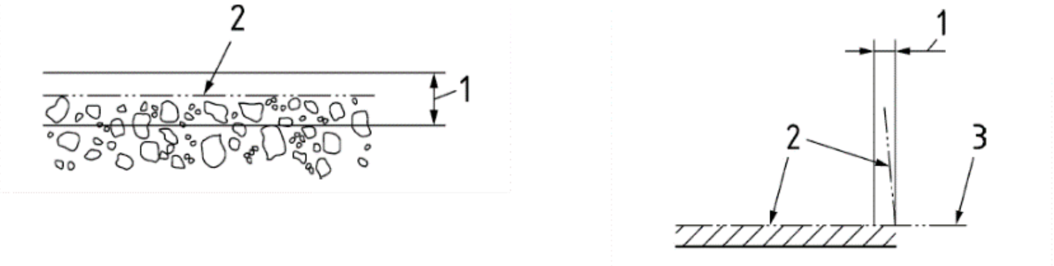
- Determination of cross-sectional area of the test specimen, by calculation, using checked, designated dimensions.
- Specimen preparation and positioning. Wipe the excess moisture from the surface of the specimen before placing it in the testing machine. Position the cube specimens so that the load is applied perpendicularly to the direction of casting.
- Loading. Select a constant rate of loading within the range 0,6 ± 0,2 MPa/s (N/mm^2·s). Record the maximum load indicated in kN at the failure of the specimen.
- Assessment of the type of failure. Examples of the failure of the specimen showing that the tests have proceeded satisfactorily are given in Fig. 6

Calculate the compressive strength using the following equation:

$$f_c = \frac{F}{A_c}, \text{ MPa} \qquad (2)$$

Where: fc – the compressive strength, in MPa (N/mm^2); F – the maximum load at failure, in N; A_c – the cross-sectional area of the specimen on which the compressive force acts, calculated from the designated size of the specimen (see according standard LST EN 12390-1), in mm^2. The area of the loading face of the cylinder or core, $Ac = \Pi \cdot d_m^2/4$ is calculated and expressed to the nearest 1 mm^2. The compressive strength was expressed to the nearest 0,1 MPa.

Fig. 5. Compression testing machine Controls 50-C4042, conforming to LST EN 12390-4



Flatness: 1- flatness tolerance;
2 - surface to which flatness tolerance applies.

Perpendicularity: 1- perpendicularity tolerance;
2 - surfaces to which perpendicularity tolerance applies;
3 - adjacent surface as datum surface

Fig. 6. Measurement of flatness and perpendicularity

Measurement of test specimen flatness and perpendicularity according to requirements of the standard LST EN 12390-1 is shown in Fig. 8. The tolerance on the flatness of the load-bearing surface is 0,0006d mm, while the tolerance on the perpendicularity of the side, regarding the end faces, is 0,007d mm. d is the nominal size for each shape of the test specimen, cube, cylinder and prism. If the flatness of the test specimen does not conform to the tolerances for designated size in LST EN 12390-1, then the specimen is adjusted. In this case, the intended load-bearing surfaces were prepared by grinding.

Equipment required for the grinding. For test specimens grinding was used C300 Specimen grinding machine, which was made by Fritschi GmbH (Germany). A simplified scheme of the specimen's grinding machine is shown in Fig. 7. Technical data of equipment: grinding wheel diameter 330 mm; grinding wheel speed 700/1400 r. p. m.; grinding wheel motor 0.75/1.5 kW; frequency 50 Hz.

Grinding procedure.

Remove specimens cured in the water of the water for grinding for not more than 1 h at a time and re-immerse in water for at least 1 h before further grinding or testing if grinding is not done with water.

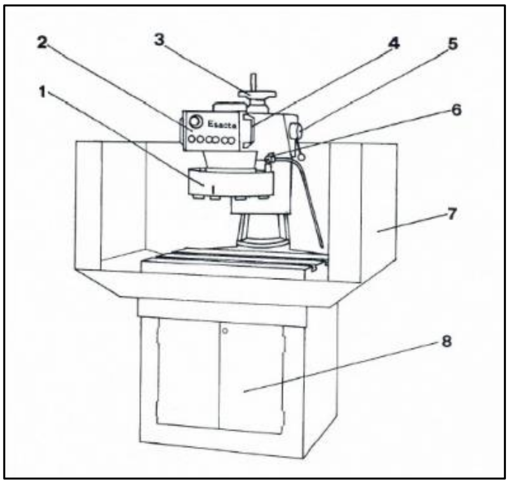


Fig. 7. Simplified scheme of the specimen grinding machine C300

1. Grinding wheel; 2. Electric controls board; 3. Handwheel for height adjustment; 4. Handle for hand feed of grinding wheel; 5. Coupling lever for automatic feed; 6. Globe valve for coolant flow control; 7. Splash guard complete with the blind; 8. Metal base with lockable storage cabinet.

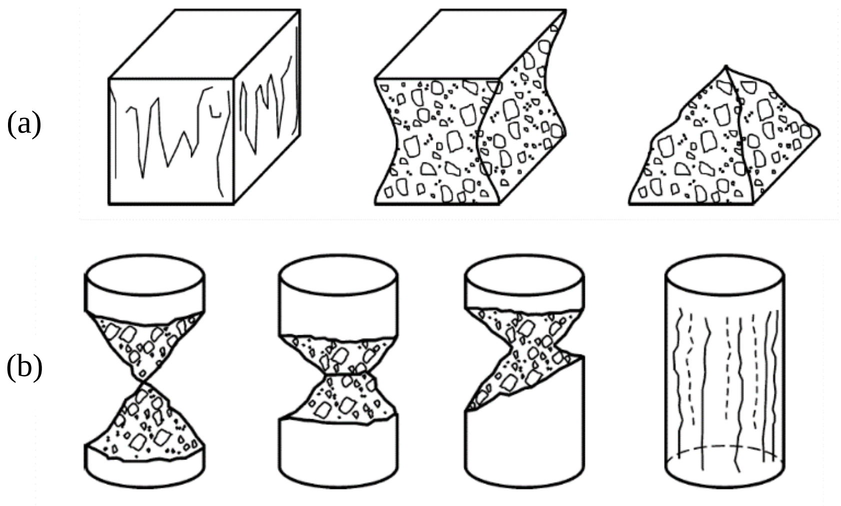


Fig. 8. Satisfactory failures of (a)cube specimens (b) cylinder specimen

2.1.3 The tensile splitting strength of test specimens

The tensile splitting strength test of hardened concrete was conducted according to the requirements of the standard LST EN 12390-6. This standard specifies a method for the determination of the tensile splitting strength of test specimens of hardened concrete. Specimens are loaded to failure in a compression testing machine conforming to LST EN 12390-4. As a tensile splitting, the testing machine was used Toni Technic press, which was made in Germany (Fig. 9).

The tensile splitting strength is given in Formula (2):

$$f_{\mathrm{ct}} = \frac{2 \times F}{\pi \times L \times d} \tag{3}$$

Where: f*ct* is the tensile splitting strength, measured in megapascals (MPa) or in Newtons per square millimetre (N/mm2); F is the maximum load, measured in Newtons (N); L is the length of the line of contact of the specimen, measured in millimetres (mm); d is the designated cross-sectional dimension, measured in millimetres (mm). The tensile splitting strength was expressed to the nearest 0,05 MPa (or N/mm2).

Fig. 9. Split tensile strength machine

2.1.4 Water absorption test

A water absorption test is a method for determination of Water Absorption, measures the amount of water that penetrates concrete samples when submerged. The Principe of water absorption test is to weight the dried samples after taking out from the oven in 110 °C, completely immerse into to the water and weight when it’s dry, and then after 15 minutes, 1 hour, 24 hours and 48 hours of water immersion. The methodology of calculation is shown by following all below steps and formulas.

- Water absorption by mass:

$$\mathrm{Wp} = \left(\frac{m48 - ms}{ms}\right) * 100,\ \% \tag{4}$$

Were,

m*48* is the weight of the sample after 48 hours soaking, g. ms is the dry mass of the sample, g.

- Density:

$$T = \left(\frac{ms}{m48 - mv}\right) * 100,\ \text{kg/m}^3 \tag{5}$$

Where, m*48* is the weight of the sample after 48 hours soaking, g. ms is the dry mass of the sample, g. mv is the sample mass in water after two days soaking, g.

- Water absorption by volume:

$$W_{p(t)} = (Wp*T)/1000,\ \% \tag{6}$$

Where, Wp is the water absorption by mass, %. T is the density, kg/m3.

- Water absorption after 15 min

$$W_1 = \left(\frac{m1s - ms}{ms}\right)*100,\ \% \tag{7}$$

Where, m15 is the weight of the sample after 15 min soaking, g. ms is the dry mass of the sample, g.

- Water absorption after 60 min

$$W_2 = \left(\frac{m60 - ms}{ms}\right) * 100,\ \% \tag{8}$$

Where, m*60* is the weight of the sample after 60 min soaking, g. ms is the dry mass of the sample, g.

- Ratio:

$$W_{1(S)} = \frac{W1}{Wp},\ \% \tag{9}$$

Where, W1 is water absorption after 15 min, %. Wp is water absorption by volume, %.

- Ratio:

$$W_{2(S)} = \frac{W2}{Wp},\ \% \tag{10}$$

Where, W2 is water absorption after 60 min, %. Wp is the water absorption by volume, %.

The porosity was calculated according to [41] :

- Total porosity:

$$Pp = \left(1 - \frac{T}{2690}\right)*100,\ \% \tag{11}$$

Where, T is the density, kg/m3.

- Open porosity:

$$Pa = Wp(t), \% \tag{12}$$

Where,

Wp (t) is the water absorption by volume, %.

- Closed porosity:

$$Pu = Pp - Pa, \% \tag{13}$$

Where, Pp is the total porosity, %. Pa is the open porosity, %.

- Frost resistance criterion:

$$Kš = \frac{Pu}{0.09xPa} \tag{14}$$

Where, Pu is the closed porosity, %. Pa is the open porosity, %.

2.1.5 The freeze-thaw resistance with de-icing salts of hardened concrete

The freeze-thaw resistance with de-icing salts of hardened concrete was conducted according to the requirements of the European standard CEN/TS 12390-9 CDF testing. This standard describes the testing of the freeze-thaw scaling resistance of concrete with sodium chloride solution. It can be used either to compare new constituents or new concrete compositions against a constituent or a concrete composition that is known to give adequate performance in the local environment or to assess the test results against some absolute numerical values based on local experiences.

Equipment required for the test. Equipment for making cores eaccording to European standard LST EN 12390-2. Climate-controlled room or chamber with a temperature of (20±2) °C, relative humidity of (65±5) %. Freezing medium, consisting either of 97 % by mass of tap water and 3 % by mass of NaCl (for the test with de-icing salt) or of de-ionized water only (for the test without de-icing salt). Freezing chamber with temperature and time-controlled refrigerating and heating system with a capacity such that the time-temperature curve presented in this standard can be obtained in the specimen, regardless of its position in the chamber. Balance, with accuracy within ± 0.05 g.

Testing procedure:

- During the first day after casting the cubes are stored in the moulds and protected against drying by use of a polyethylene sheet. The air temperature is (20±2) °C. After (24±2) h, the cubes are removed from the moulds and placed in a bath with tap water having a temperature of (20±2) °C. When the cubes are 7 d old, they are removed from the water bath and placed in the climate chamber, where they are stored until the freeze-thaw testing starts. At (28±1) day specimens were put into chamber described in Fig. 10. One cycle freezing control temperature are described in Fig. 11.

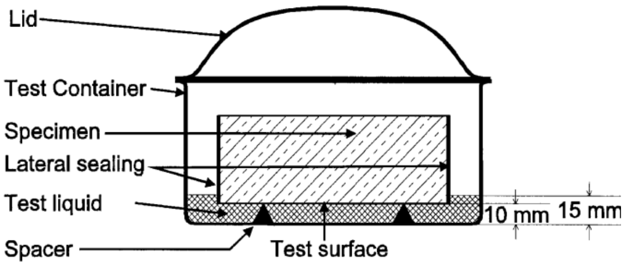


Fig. 10. The test set-up was used for the freeze-thaw test.

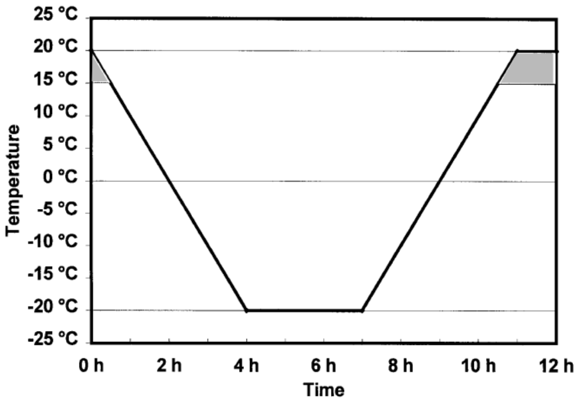


Fig. 11. Freezing-thawing temperature cycle.

- After (7±1), (14±1) and (28±1) cycles, was carried out the following procedure for each specimen during the thawed phase of the solution between 20 h to 24 h. During intermediate freezing thawing testings was checked samples visually and tried to obtain sample damages which was occurred during freezing thawing process - cracks, scalings from cement stone or aggregate particles.
- Before freezing and after 28 freezing-thawing cycles samples was weighed to the nearest 0,1 g. The cumulative mass of the dried scaled material after the n freeze-thaw cycle is determined by the equation (3). Record the value rounded to the nearest.

$$m_{s,n} = m_{s,after} - m_{s,before} \tag{15}$$

where: $m_{s,n}$ - the cumulative mass of sample after n freeze-thaw cycles rounded to the nearest 0,1 g; $m_{s,\ before}$ - the cumulative mass of sample calculated at the previous measuring occasion; $m_{s,\ after}$ - the cumulative mass of sample calculated after freezing thawing test;

- For each measurement and each specimen calculate Sn, the cumulative amount of scaled material per unit area after n cycles, in kilograms per square meter, by the following equation:

$$S_n = \frac{m_{s,n}}{A} \cdot 10^3 \tag{16}$$

Where: Sn - the mass of scaled material related to the test surface after the n-th cycle in kg/m^2; $m_{s,n}$ - the cumulative mass sample scaled material after n freeze-thaw cycle determined by Formula (4); A - the effective area of the testing surface, calculated from the length measurements and rounded to the nearest 100 mm^2.

2.2 Preparation of mixtures

The concrete mixture preparation (Table 1) process involves three sets, with the first set comprising four distinct batches of mixtures, each varying in water-cement content ratios, aimed at determining the optimal mix for achieving desired properties. These four mixture sets are denoted as RCC-W0.30, RCC-W0.35, RCC-W0.40, and RCC-W0.45, all containing 300 Kg/m^3 of cement and aggregate (0/4mm-45%, 2/8mm-15%, 8/16mm-40%), [14] (Fig. 2-3) with the water-cement ratios adjusted to

0.30, 0.35, 0.40, and 0.45, respectively. The second set comprising three distinct batches of mixtures, each varying in cement content. These three mixture sets are denoted as RCC-C280, RCC-C300 and RCC-C320, all containing 0.425 of water cement ratio and aggregate (0/4mm-45%, 2/8mm-15%, 8/16mm-40%), with the cement content adjusted to 280 Kg/m^3, 300 Kg/m^3 and 320 Kg/m^3, respectively. The third set comprising three distinct batches of mixtures, each varying in fly ash content. These three mixture sets are denoted as RCC-F10, RCC-F20 and RCC-F30, all containing 0.425 of water cement ratio and aggregate (0/4mm-45%, 2/8mm-15%, 8/16mm-40%), with the fly ash content adjusted to 10%, 20% and 30%, respectively [34] (Fig. 12-14).

Table 2. Mix proportions of RCC mixtures

Mixture	Water Cement Ratio	Cement Kg/m^3	Fly ash kg	Fine aggregate 0/4 mm (kg)	Coarse aggregate 2/8 mm (kg)	Coarse aggregate 8/16 mm (kg)	Admixture HC44-12 %	Admixture LPSA10 %
RCC-W0.30	0.300	300	-	934	311	830	0.4	0.2
RCC-W0.35	0.350	300	-	916	305	814	0.4	0.2
RCC-W0.40	0.400	300	-	898	299	798	0.4	0.2
RCC-W0.45	0.450	300	-	879	293	782	0.4	0.2
RCC-C280	0.425	280	-	907	302	806	0.4	0.2
RCC-C300	0.425	300	-	889	296	790	0.4	0.2
RCC-C320	0.425	320	-	871	290	775	0.4	0.2
RCC-F10	0.425	279	31	880	293	783	0.4	0.2
RCC-F20	0.425	248	62	880	293	783	0.4	0.2
RCC-F30	0.425	217	93	880	293	783	0.4	0.2

Fig. 12. Materials for batch 01 RCC-W0.30, W0.35, W0.40, W0.45

Fig. 13. Materials for batch 02 RCC-C280, C300, C320

Fig. 14. Materials for batch 03 RCC-F10, F20, F30

2.3 Specimen Preparation

The concrete mixture was prepared using a laboratory Zyklos rotating pan mixer ZZ 50 HE according to EN 206. Cylindrical specimens of the following size of diameter 100mm x height 100mm were prepared according to ASTM C1800 (ASTM2016). For specimen preparation, RCC mixtures of 1.8 Kg were poured in a single layer in cylindrical mould of gyratory compactor. The gyratory compactor parameters used for preparation of specimens were 69 kPa of pressure, gyratory angle 1.43 and 60 cycles [20] (Fig. 15). Following a 24-hour casting period, the specimens were kept in damp conditions at room temperature (20±3□C) for a total of 28-days.

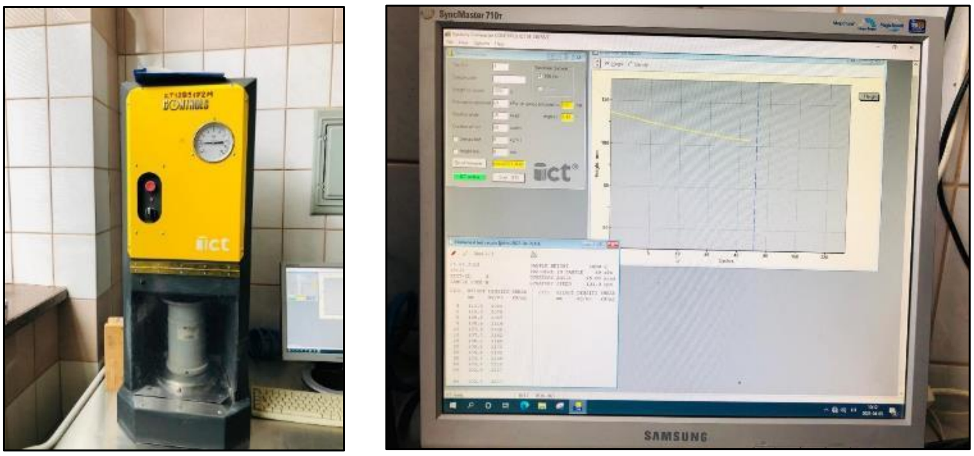


Fig. 15. Gyractory compactor

3 Results and discussion

3.1 Finger Slump Test

Another quick technique for evaluating the strength and consistency of freshly laid concrete, particularly roller compacted concrete, is a field test [27]. A small sample of newly mixed, roller-compacted concrete should be taken from the placing location, made sample into a shape of ball using and strike it firmly with finger. Observe the behaviour of the concrete. When mixed properly, Roller Compacted Concrete (RCC) formed easily into a snowball the size of a palm and broke into four separate pieces when broken with the thumb. During the test, the concrete that had a 20% fly ash content and a water-to-cement ratio of 0.425 demonstrated a more exact and accurate splitting behavior.

Fig. 16. Sample W/C:0.30 Finger Slump test

In the Fig. 16 the water cement ratio is 0.30, after the mixing concrete looks like very dry and according density parameters, compressive strength and split tensile strength these samples showed the worse results. It means with such water cement ratio was not enough moisture in the mix. Due this reason we clearly see that was not posiible to form snow ball and after finger pressure test mix completely broken.

Fig. 17. Sample W/C:0.35 Finger Slump test

In comparison to RCC-W0.30 (Fig. 16), RCC-W0.35 (Fig. 17) has a little higher water content, making it more suitable for creating snowballs. However, the RCC-W0.35's finger pressure test is likewise flawed. In addition, compared to RCC-W0.30, the density parameters, compressive strength, split tensile strength, and theoretical flexural strength nonetheless, they did not reach the characteristics of regular concrete. Consequently, a 0.35 water-to-cement ratio is insufficient.

Fig. 18. Sample W/C:0.40 Finger Slump test

Snowballs are better made using RCC-W0.40 (Fig. 18) because of its 0.40 water content. It only broke into two pieces during the finger slump test, demonstrating that the water concentration in this mixture is sufficient. It is therefore clear from this mixture that the values of the mechanical and physical qualities increase with an increase in the water-to-cement ratio.

Fig. 19. Sample W/C:0.45 Finger Slump test

The greater water content of RCC-W0.45 (Fig. 19) makes it simple to make snowballs, and it also caused it to split into two pieces in the finger slump test. However, the concrete's characteristics matched those of regular concrete.

From the above mix, the optimum water-cement ratio is 0.425 because this ratio has a cement content of 300 kg/m3, which gives it more physical and mechanical properties when compared to other mixes.

Fig. 20. Cement content:280 Kg/m^3 Finger Slump test

Using a finger slump test, the RCC-C280 (Fig. 20) with a water-cement ratio of 0.425 splits into two pieces, one of which is completely broken, and its compressive strength is lower than that of the RCC-C300 and RCC-C320. The low cement content is the reason for this.

Fig. 21. Cement content:300 Kg/m^3 Finger Slump test

In RCC-C300, having a water-cement ratio of 0.40 gives a little less density when compared to RCC-C320. In the snowball finger slump test, it was also cut into only two pieces. And all other concrete parameters have higher values when compared to other mixes (Fig. 21).

Fig. 22. Cement content:320 Kg/m^3 Finger Slump test

The RCC-C320 (Fig. 22), by doing the finger slump test, is split perfectly into three pieces, showing good concrete. But compared to other mechanical and physical properties, the values are lower when compared to RCC-C300, except density. From these three mixes, we conclude that the optimum cement content is 310 kg/m^3.

Fig. 23. Flyash content:10% Finger Slump test

In RCC-F10 (Fig. 23), the cement is replaced with flyash at 10%. When conducting the finger slump test, it does not split correctly, which is shown by adding flyash at 10% to the density, and concrete properties are also decreasing

Fig. 24. Flyash content:20% Finger Slump test

In the mix having flyash content of 20% (Fig. 24) by making snowballs and finger pressure, it split better than flyash having 10% and 30%. Also, the density parameters, compressive strength, split tensile strength, and therotical flexural strength are also better.

Fig. 25. Flyash content:30% Finger Slump test

In RCC-F30 (Fig. 25), by conducting a finger slump test, it did not split better than RCC-F20, and the concrete parameters were also decreasing while increasing flyash content by 20%. From the above discussion, we can partially replace cement with 20% flyash, which gives good durability to road pavements.

3.2 Visual Analysing

The RCC surface's visual inspection is a crucial field test. It entails looking over the surface to look for any obvious flaws such fractures, cavities, segregation, or unevenness. A visual inspection offers a preliminary evaluation of the RCC's quality once it had been installed.

Fig. 26. W/C;0.30 Visual Analysing test

In RCC-W0.30 (Fig. 26), the specimen shows that it was taken directly from the gyratory compactor, and the density given by the compactor is very low, which is why, in visual analysis, it has too many pores and honeycombs. The low water cement ratio is the main reason, and for RCC, this water cement ratio is not adequate.

Fig. 27. W/C:0.35 Visual Analysing test

Increasing the water cement ratio up to 0.35 for RCC-W0.35 by visual analysis (Fig. 27), it also has pores, but it is low when compared to RCC-W0.30. Hence, the concrete parameters were also increased by adding water.

Fig. 28. W/C;0.40 Visual Analysing test

For RCC-W0.40, the sample (Fig. 28) looks good when compared to other mixes, but the density of concrete is low.

Fig. 29. W/C;0.45 Visual Analysing test

For RCC-W0.45 (Fig. 29), the sample looks good when compared to other mixes, but the high water-to-cement ratio causes too much wetness on the surface of the specimen. It affects the strength properties of concrete, and it is not possible to compact with vibratory rollers.The water-to-cement ratio of 0.425 is the optimal water content that is obtained from visual analysis.

Fig. 30. cement Content 280Kg/m^3 Visual Analysing test

Cement content of 280 kg/m3 with a water-to-cement ratio of 0.425 after specimen preparation, it has honeycombs because of the low cement content, and the concrete properties are also low (Fig. 30).

Fig. 31. Cement Content 300Kg/m^3 Visual Analysing test

In RCC-W300 (Fig. 31), the sample has no pores and is visually pleasing, it looks good, and the strength properties and density are lower when compared to RCC-W320.

Fig. 32. Cement Content 320Kg/m3 Visual Analysing test

The mix containing 320 kg/m3, showing little desnity, is higher when compared to RCC-W300 and its looks like good (Fig. 32).

Fig. 33. Fly ash content 10% Visual Analysing test

The density is decreasing by adding flyash and other concrete parameters as well. By visual analysis, after getting from the compactor, it also has some pores and honey combs, which also reduce the properties of concrete (Fig. 33).

Fig. 34. Fly ash content 20% Visual Analysing test

Fig. 35. Fly ash content 30% Visual Analysing test

At a water content of 0.425, the concrete's appearance is notably enhanced when incorporating fly ash at a 20% concentration, showcasing a more distinct visual appeal compared to mixes containing 10% or 30% fly ash (Fig. 34-35).

3.3 Density

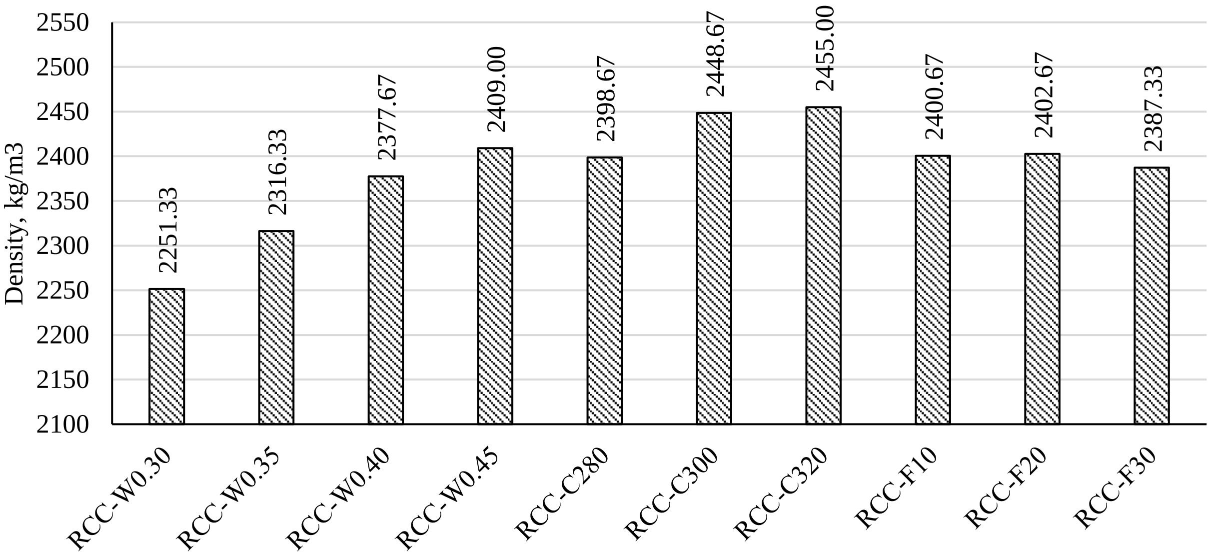


Fig. 36. Graph showing RCC mixtures vs Density.

The density results are obtained directly from the gyratory compactor. From the Fig.36, the density of concrete is increasing with an increasing water-to-cement ratio. At a water-to-cement ratio of 0.425, it shows a higher density when compared to 0.40 and 0.45 water-to-cement ratios because in specimen RCC-W40, the required amount of water is less for the hydration process, and in specimen RCC-W0.45, the water content is so high that it mades high pores in the concrete. When we add more cement, 300 to 320 kg/m^3, with a water-to-cement ratio of 0.425, the density increases by only 0.25%, and both mixes achieve the density property of standard concrete. From this result, we conclude that the cement content of 310 kg/m^3 had good property for concrete. To replace cement with 20% fly ash, this gives a good density compared to RCC-F10 and RCC-F30. This is because in RCC-F20, more pozzolanic reactions take place [35].

3.4 Compressive strength

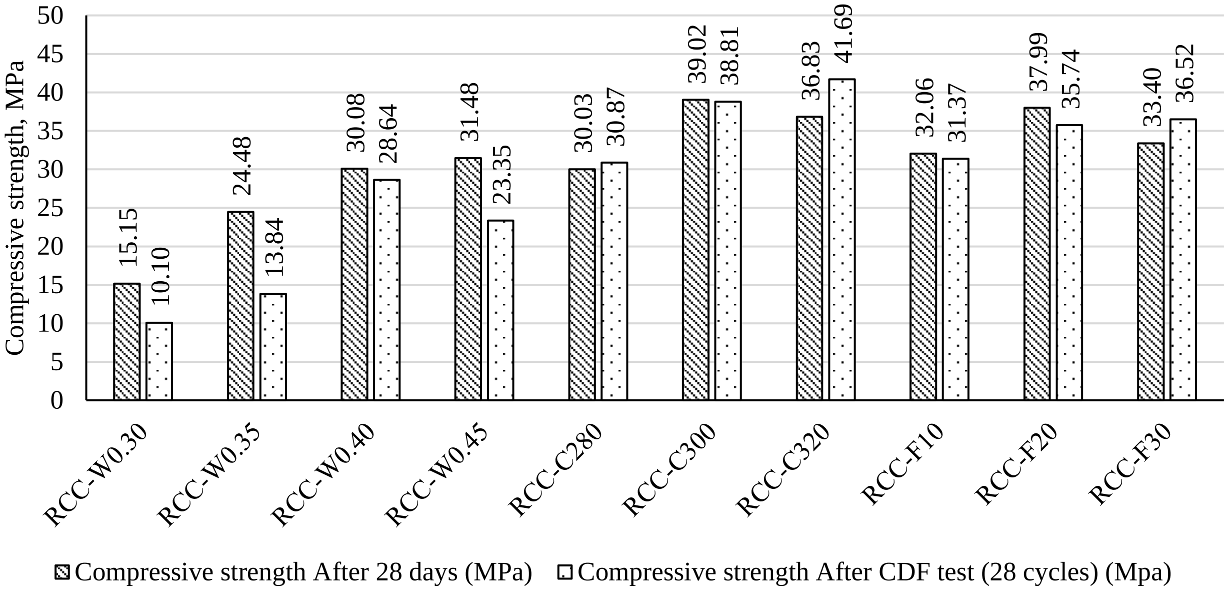


Fig. 37. Graph showing RCC mixtures vs Compressive strength.

Compressive strength tests as per EN 12390–3. The specimens are tested at 28th day after casting. The compressive strengthtests a compression machine that have maximum 2000 kN loading capacity was used, and maximum load values obtained during the tests were recorded [36] [8]. Fig. 37 represents the compressive strength test is conducted as per [37] and graph of the specimens after 28-days and after the CDF test (28 cycles). From this, RCC-C300 gives more compressive strength compared to other mixes, but by substituting fly ash for 20% of the cement, RCC-F20 compressive strength is decreasing by 2.62%. Comparing the specimens RCC-F10 and RCC-F30, compressive strength is low. After the CDF test, the compressive strength of concrete with a minimum cement content of 300 kg/m^3 and a 0.425 water-to-cement ratio was also replaced by fly ash at 10%, 20%, and 30%. The compressive strength was changed only from -2.0% to +2.0%. [17]

3.5 Split tensile strength and theoretical flexural strength

The splitting tensile strength test is to determine the split tensile strength of concrete. The concrete strength is affected by changing the water to cement ratio and ingredient proportioning. This had an impact on the durability, stability and strength. According to Fig. 38, the split tensile strength is increased by increasing the water content to the point of a water-to-cement ratio of 0.425. After that, the split tensile and theoretical flexural strength are decreasing, regardless of the increase in cement content or water-to-cement ratio. While RCC-F10 shows a good result compared to other mixes that contain fly ash, from the graph, both split tensile and theoretical flexural strength are decreasing with increasing fly ash content in concrete. The corelation of split tensile strength theoretical flexural strength equation (1) taken from the literature [38]

$$F_{ft}=1.63(f_{spt})^{0.89} \quad R^2=0.90 \qquad (15)$$

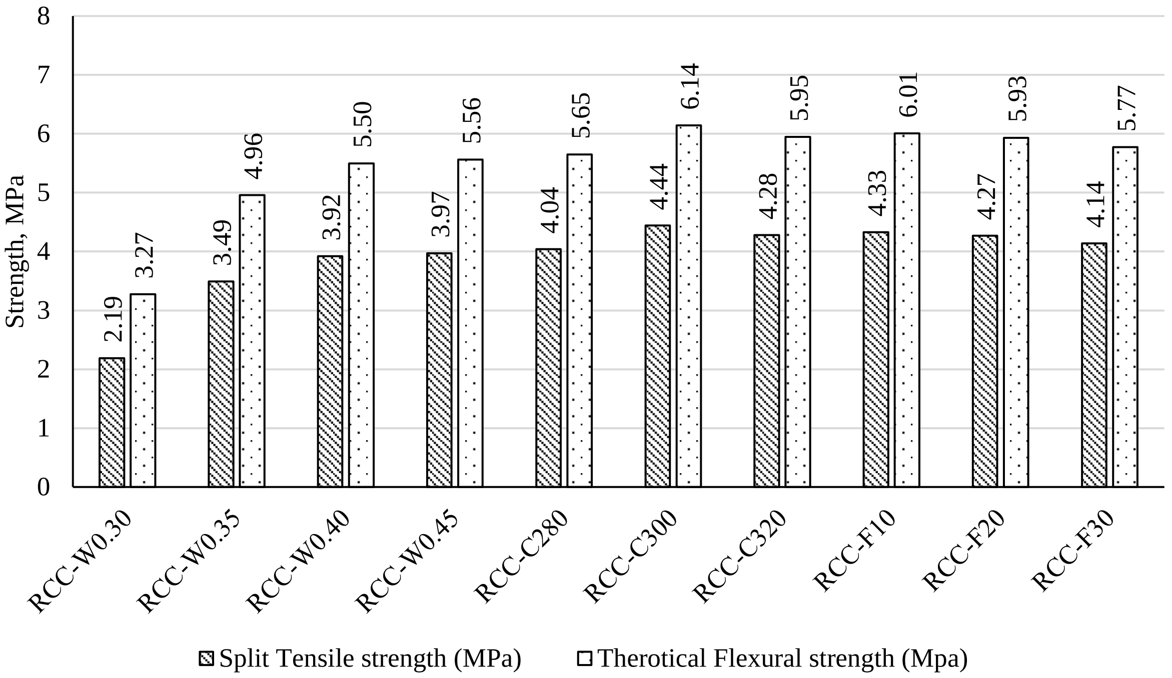


Fig. 38. Graph showing RCC mixtures vs split tensile and flexural strength.

3.6 Water Absorption Test

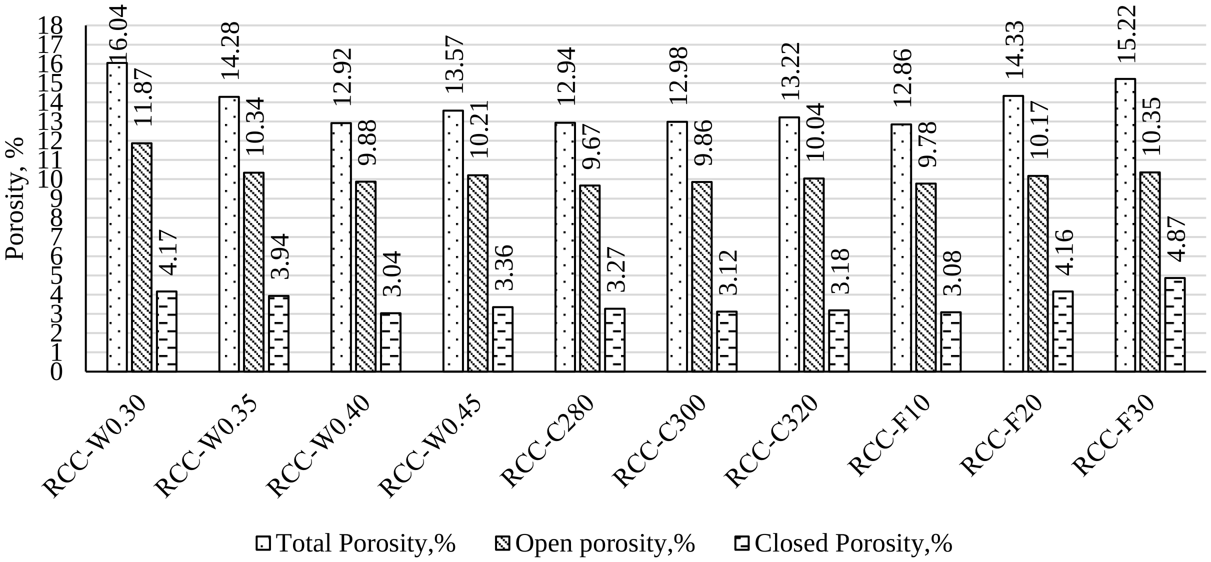


Fig. 39. Graph showing RCC mixtures vs porosity.

Concrete's water absorption test is a crucial evaluation technique that is frequently used in the building and civil engineering sectors. It is quite important for figuring out the permeability, longevity, and general quality of concrete specimens. In this test, concrete samples are submerged in water for a normal 24-hour period, and the amount of water absorbed is then measured. In order to evaluate the concrete's long-term performance and suitability for different building applications, the results provide crucial information regarding the concrete's resistance to moisture penetration. The Water Absorption Test in Concrete, which is a key component of your thesis and supports your overall research goals, offers insightful information about the properties of the material. From Table 3 and Fig. 39, porosity is increasing by lowering the water-cement ratio, and closed porosity is also decreasing. While substituting fly ash, it shows an increase in total porosity as well as closed porosity by increasing fly ash content. The increase in closed porosity results in reduced capillarity action, which helps increase the durability of pavement. Water absoption testing photos described in Fig. 40.

Table.3. Determination of closed/open porosity of concrete by water absorption kinetics

Samples	Wp,%	Density, kg/m^3	Wp(t),%	W_{t1},%	W_{t2},%	W_{t3},%	Prediction of freezing	Freezing cycles
	After 48h	Dry test	Bulk intake of water	After 15min	After 1h	After 24h		F, in cycles
RCC-W0.30	5.26	2258.49	11.87	4.49	4.75	5.22	3.90	625.12
RCC-W0.35	4.49	2305.84	10.34	3.64	3.92	4.48	4.24	673.94
RCC-W0.40	4.22	2342.41	9.88	2.75	3.33	4.29	3.42	548.68
RCC-W0.45	4.39	2324.86	10.21	2.51	3.02	4.51	3.65	587.21
RCC-C280	4.13	2342.01	9.67	2.54	2.97	4.22	3.75	602.90
RCC-C300	4.21	2340.84	9.86	2.44	2.85	4.33	3.52	565.06
RCC-C320	4.30	2334.34	10.04	2.42	2.93	4.40	3.52	565.99
RCC-F10	4.17	2344.10	9.78	2.47	2.92	4.27	3.50	562.50
RCC-F20	4.42	2304.45	10.17	2.54	2.73	4.50	4.54	711.50
RCC-F30	4.54	2280.47	10.35	2.49	2.57	4.66	5.23	779.73

Fig. 40. Water absorption test.

3.7 Deicing solution and freeze thaw resistance (CDF) test

A major evaluation procedure that is often used in concrete research and construction is the test method for freeze-thaw resistance of concrete using sodium chloride solution (CDF) as per eurocode LST EN 13877-1. It is intended to assess concrete's resilience to the damaging effects of frequent freezing and thawing cycles, which is important in cold areas. In order to simulate the corrosive effects of freeze-thaw cycles, concrete specimens are submerged in a sodium chloride solution during the CDF test. The test's findings provide critical information about the resilience and performance of concrete in challenging environmental circumstances. The CDF test is a crucial component of your thesis since it offers insightful information to back up your study of concrete resilience and its real-world applications in areas vulnerable to freeze-thaw-induced damage. The CDF tested conducted as per the literature [39] CDF test the mass of the concrete is decreasing while increasing water content. Having a water cement ratio of 0.425 and cement content between 280 Kg/m3 and 320 Kg/m3 specimens does not show any loss of weight. By introducing fly ash into concrete also does not show any loss of weights [40] (see Table 4 and Fig. 41-44).

Table 4. Mass loss of specimen after CDF test

Mixture	Mass Before Test (kg)	Mass After 28 cycles	Mass Loss per area (kg/m^2)
RCC-W0.30	1.812	1.758	-1.136
RCC-W0.35	1.834	1.782	-1.121
RCC-W0.40	1.816	1.805	-0.243
RCC-W0.45	1.812	1.809	-0.065
RCC-C280	1.807	1.810	0.063
RCC-C300	1.803	1.806	0.064
RCC-C320	1.799	1.802	0.057
RCC-F10	1.807	1.809	0.037
RCC-F20	1.798	1.802	0.095
RCC-F30	1.797	1.801	0.086

Fig. 41. Specimen wrapped with Nacl Solution for CDF test.

Fig. 42. Set 01, Before & After CDF test

Fig. 43. Set 02, Before & After CDF test

Fig. 44. Set 03, Before & After CDF test

4. Result

From the graph 1 gives the minimum moisture content of 0.425 and from the graph 2 minimum cement content is 310kg/m^3. So with this mix proportion gives good compressive and split tensile strength as shown in Fig. 37-38. The new mix design for Roller Compacted Concrete is

- Cement Content : 248 Kg/m^3
- Flyash : 62Kg/m^3
- Water/ cement ratio : 0.425
- Fine aggregate (0/4) : 880 Kg
- Coarse Aggregate (4/8) : 293 Kg
- Coarse Aggregate (8/16) : 783 Kg

4.1 Project site investigation

- Location : Palemono.g, Kaunas (Fig. 45)

- Area to be concrete: $10000m^2$
- Thickness of concrete: 0.40m
- Usage of cement: 360 Kg/m^3
- Total cement: 1440 Tonnes
- Concrete class: 30/37

Fig. 45. Project site, Palemono.g, Kaunas

During the construction process the RCC mix is continually placed using a three step cycle. This cycle involves production, site transportation spreading and compaction. Continuous placement of the RCC layer means it is placed directly on top of the preceding layer. There are three used methods, for batching and mixing Roller Compacted Concrete (RCC); tilt drum mixers, transit mixers or pugmill mixers. On the hand pugmill mixers (Fig. 46-47) are referred to as flow plants because materials are dumb into the mixer at the same rate that RCC is moved from it. Continuous flow plants have a production capacity. Ensure excellent mixing efficiency, with total mixing times typically ranging between 10 and 30 seconds.

Fig. 46. Batching plant

Order :2254 >> 100
Recipe :Volujamas
Ordered : 11.0m³
Finished : 0.0m³

Fig. 47. Concrete batching plant system monitor

A computer supported electronic control system enables the preparation of concrete to be done either automatically or manually depending on the requirements. RCC can be transported using both transit mixers and dump trucks, which's the method of transportation. The factors like distance between the plant and the concrete paving speed, climate conditions and time of day will influence the number of trucks needed and their scheduling. It is important to clean the trucks to prevent RCC contamination by washing away any remnants, from loads (Fig. 48).

Fig. 48. RCC dumped in truck

Run the snowball test and to ensure compaction it is important that the RCC (Roller Compacted Concrete) is positioned to 80% of the desired wet density using an asphalt paver (Fig. 49). The paver should continuously move forward. The hopper should not keep to empty. This practice helps prevent issues, like segregation or uneven surfaces. Compaction is a step when constructing an RCC pavement as it significantly impacts the pavements strength, durability, permeability, smoothness and other hardened characteristics.

Fig. 49. RCC Snow ball test

After achieving the required density surface cracks and tears can be. A tight smooth surface can be achieved using either a vibratory drum roller or a rubber tyre roller. Typically, a 10-ton dual drum vibratory roller is running after placement (Fig. 50-52). In confined spaces or areas, near obstacles like curbs and gutters hand compactors prove to be quite useful. It's important to note that dry RCC may appear dusty or grainy and lead to surface tearing while wet RCC may exhibit a finishing appearance and display the behavior during compaction. Both scenarios can result in segregation making it challenging to achieve the required density. Compaction should ideally be finished within 15 minutes of paving and 45 minutes of mixing. When operating a compactor, near an edge operators must exercise caution to prevent vibration that could potentially cause edge collapse.

Fig. 50. RCC Paver machine

Fig. 51. RCC Roller compactor machine

Fig. 52. RCC Rubber tyre roller compactor machine

The RCC surface assumed the appearance depicted in Fig. 53 after the initial cycles of compaction using a roller-compacted machine. With additional compaction using roller-compacted concrete machinery, the RCC face assumed the appearance depicted in Fig. 54. With the use of a rubber tire roller, the RCC surface was later altered to resemble Fig. 55.

Fig. 53. RCC after running roller compactor machine

Fig. 54. RCC after running rubber tyre roller compactor machine

Fig. 55. RCC after final finishing

My research indicates that this project could save a significant 448 tonnes of cement if fly ash were used in place of 20% of the cement. This program not only lowers project costs overall but also considerably lessens its negative environmental effects, demonstrating the combined advantages of cost savings and environmental friendliness through resource conservation.

4.2 Advantages of RCC

4.2.1 Speed of Construction

One of the benefits of RCC pavement is its ability to be constructed faster and more cost effectively compared to concrete or other types of asphalt pavement. This is achieved by utilizing paving equipment and rollers similar, to those used for high density asphalt, which efficiently compact the concrete minimizing the need for finishing and forming processes. RCC pavement can often be completed in a pass. In cases where exceptionally heavy-duty pavements require a thickness exceeding ten inches it may be necessary to utilize two layers. Moreover, due to its compaction and density RCC pavement offers load bearing capacity. Is often ready for use within twenty-four hours, after placement.

4.2.2 Sustainability

RCC pavements are environmentally friendly. To make them we can use materials like fly ash which decrease the amount of cement needed in the RCC mix. This in turn lowers the embodied energy of the pavement. Additionally, the lighter color of RCC pavements provides light reflectivity making environments safer and brighter while reducing the need, for lighting. In reality RCC pavements save, up to thirty seven percent of energy since they allow for wattage lighting or require light fixtures overall. Moreover, because RCC is light colored it absorbs heat. Keeps community’s cooler.

4.2.3 Low Maintenance

Similar, to concrete Roller Compacted Concrete (RCC) experiences repair needs throughout its lifespan. There is no requirement for seal coating or resurfacing. Moreover maintenance, for RCC is minimal mostly limited to vacuuming or sweeping.

4.2.4 Durability

Roller compacted concrete (RCC) is known for its durability making it capable of withstanding the weight of passing vehicles without showing signs of wear and tear. It can easily handle axle loads. Remains intact even when cars brake or make turns. Moreover, RCC exhibits durability to concrete pavement enduring extreme temperatures ranging from 60 degrees, in winter to 80 degrees in summer. It also displays resistance against substances like fuels, oils, solvents and fluids. With design considerations an RCC pavement can easily serve for, over two decades.

4.2.5 Competitive Cost

RCC offers advantages in terms of cost savings. In the past the pricing of RCC has been comparable, to that of asphalt pavement. However due to the increasing costs of oil and asphalt RCC may now be an option, in terms of initial paving expenses. In fact, when compared to paving RCC can save costs by approximately twenty to thirty percent. Moreover, owners recognize the long-term cost benefits associated with RCCs maintenance requirements.

4.2.6 Safety

Compared to colored asphalt colored RCC surfaces are much easier to spot at night. Whats more they maintain their surface integrity. However, the presence of rust, from vehicles can pose a danger on asphalt roads during snowy or icy conditions. RCC significantly reduces the need for maintenance and resurfacing thereby enhancing the safety of your work zone configurations. It is crucial to prioritize safety when undertaking road construction projects. Utilizing software, for scheduling subcontractors can greatly assist in managing all safety related concerns. This dedicated software tool minimizes the risk of accidents by ensuring that all necessary safety precautions are properly implemented.

4.3 Disadvantages of RCC

1. Due, to the requirement of a mix that can be compacted using rollers RCC offers a more limited range of design options compared to traditional concrete.
2. Use case; The RCC method may not be suitable, for all types of projects. Is most commonly employed in the construction of large-scale structures such, as industrial pavements, levees and dams.
3. It can be quite challenging to work in intricate spaces due, to the limited maneuverability and the complexity of shapes involved.
4. Since a ratio of water to cement is used in its construction, there is a chance that its durability will be lowered.
5. It can be difficult to place and compact materials when there are temperature changes.
6. RCC that has pozzolanas present is more vulnerable to damage from freezing temperatures. This happens because the pozzolanas content slows down the development of strength.
7. Mixtures are an option for bedding with varying degrees of consistency. Controlling the amount of time between each lift is crucial. We should also think about offering joint treatment. Lastly, adding more content to the mixture might be advantageous.

Conclusions

1. RCC tends to exhibit low density characteristics when the water content is over 45%, which may have an impact on the overall quality and performance of the concrete. Increased porosity, decreased compaction, and decreased strength qualities can result from too much water in the concrete mix. The extra water leaves gaps in the matrix of the concrete, making it less thick and more brittle. The long-term performance, load-bearing capabilities, and durability of the roller-compacted concrete may be affected by this. In order to achieve the appropriate density and strength requirements, it is crucial to carefully manage and optimize the water content during the mixing and installation process.
2. The density results obtained with the gyratory compactor offer important information on how concrete behaves in relation to the ratio of water to cement. The data clearly shows a trend: an increase in the water-to-cement ratio is consistently accompanied by an increase in the density of the concrete. This equation shows a clear peak where the concrete reaches its maximum density at a particular ratio of 0.425. This discovery suggests an optimum position within the evaluated parameters, when the interaction between cement and water reaches a perfect equilibrium and results in the maximum density. After reaching this apex, the density gradually starts to decrease as the water-to-cement ratio continues to rise. This decrease implies that, even with more water content, there is a decreasing benefit in terms of density.
3. Density is somewhat increased by raising the cement content from 300 to 320 kg/m³ at a ratio of 0.425; the ideal density is 310 kg/m³. This marginal increase points to a limit at which adding more cement (above 310 kg/m³) produces decreasing benefits in terms of density improvement, highlighting 310 kg/m³ as the ideal content in this particular ratio. This result emphasizes a critical tipping point, indicating that more cement additions may not greatly increase density. It also emphasizes how efficient and effective 310 kg/m³ is in maximizing density within the given ratio range.
4. Up to the 0.425 water-to-cement ratio, the split tensile strength shows an increasing pattern, indicating progress. But above this point, changes in cement or water content don't maintain this improvement; instead, they cause the split tensile strength to start to decrease. There is a clear limit to the strength that may be achieved because this drop continues even with more cement or water content. This discovery highlights how important the 0.425 ratio is for optimizing split tensile strength. It also emphasizes that deviations from this ratio prevent the strength from being enhanced, indicating a complex interaction between cement, water, and the material's structural integrity.
5. Adding fly ash to concrete increases its total and closed porosity, which affects capillarity. This modification has the potential to improve pavement durability even while it increases porosity. The microstructure of the concrete is changed by the addition of fly ash, which affects the capillary network. Although this modification increases the amount of porosity, it also helps to reduce the possibility of damage by strengthening the concrete's defense against some harmful elements. Thus, this change in porosity caused by the fly ash addition is a possible way to support pavement longevity even if the original increase in porosity was initially more than zero.
6. A higher water content in the CDF test is associated with a lower concrete mass. On the other hand, specimens with a cement concentration of between 280 and 320 kg/m³ and a ratio of 0.425 maintain their weight. This particular combination of a 0.425 ratio and different cement concentration creates a threshold that demonstrates resistance to mass loss even with changes in water content. This resilience suggests a vital equilibrium, demonstrating the importance of this

ratio and cement range in retaining weight during the CDF test, by interacting to counteract the negative effects of rising water and preserve concrete mass.

7. These findings suggest an optimal mix with 248 kg/m^3 cement content, 0.425 water cement ratio and 62Kg/m^3 fly ash may enhance density and durability in pavement construction.
8. When introduce 20% fly ash with cement, the total CO2 emissions is reduced and it helps to sustainable and ecofriendly construction.

List of references

1. D. RAMBABU, et al. *Evaluation of Roller Compacted Concrete for its Application as High Traffic Resisting Pavements with Fatigue Analysis.* p. 2-3(2023)10.1016/j.conbuildmat.2023.132977.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85169545685&doi=10.1016%2fj.conbuildmat.2023.132977&partnerID=40&md5=9db07a564a9c7634a8981990e5d55ff1.

2. C. CHHORN, et al. *Evaluation on Compactibility and Workability of Roller-Compacted Concrete for Pavement.* 208p. 905-10(2019)10.1080/10298436.2017.1366762.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85028563736&doi=10.1080%2f10298436.2017.1366762&partnerID=40&md5=35d1436c3287564f8d0558b833105078.

3. J. PAINO, et al. *Impact of Fly-Ash on Carbon Emissions in Different Concrete Grades.* p. 374(2019)10.31705/WCS.2019.37.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85113154537&doi=10.31705%2fWCS.2019.37&partnerID=40&md5=2cf2dc7fca889eed32d8ebbba05c0ae9.

4. S.-. PARK. *Journal of CO2 Utilization: Editorial.* p. 6(2013)https://www.scopus.com/inward/record.uri?eid=2-s2.0-84883197282&doi=10.1016%2fS2212-9820%2813%2900020-6&partnerID=40&md5=2f1d83c6dcc240d1d5f580669afec0b5.

5. W. Tayabji and D. Sherman. *Report on Roller-Compacted Concrete Pavements ACI Committee* . p. 325(2001).

6. M. SELVAM and SINGH, S. *Comparative Investigation of Laboratory and Field Compaction Techniques for Designing Roller Compacted Concrete Pavements (RCCP).* p. 3(2023)https://www.scopus.com/inward/record.uri?eid=2-s2.0-85148695981&doi=10.1080%2f10298436.2023.2177850&partnerID=40&md5=547a0c0439b1f77cfd650df2f4efd8db.

7. IOWA State University. *Guide for Roller-Compacted Concrete Pavements.* p. 1-6(2010).

8. Y. ABUT, et al. *A Comparative Study on the Performance of RCC for Pavements Casted in Laboratory and Field.* 236p. 1777-90(2022)10.1080/10298436.2020.1823391.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85091608046&doi=10.1080%2f10298436.2020.1823391&partnerID=40&md5=82eaed62d127ef16fd976fea17426a1b.

9. S. HUSEIN BAYQRA, et al. *Physical and Mechanical Properties of High Volume Fly Ash Roller Compacted Concrete Pavement (A Laboratory and Case Study).* 314(2022)10.1016/j.conbuildmat.2021.125664.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85119194061&doi=10.1016%2fj.conbuildmat.2021.125664&partnerID=40&md5=bcf4c8b7fd21ba0bc69de2924fe9c5e1.

10. P. SHAFIGH, et al. *Optimum Moisture Content in Roller-Compacted Concrete Pavement.* 2114p. 1769-79(2020)10.1080/10298436.2019.1567919.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85060952181&doi=10.1080%2f10298436.2019.1567919&partnerID=40&md5=106f511a805f274ce57088643378 26d8.

11. A. AGHAEIPOUR and MADHKHAN, M. *Mechanical Properties and Durability of Roller Compacted Concrete Pavement (RCCP)–a Review.* 217p. 1775-

98(2020)10.1080/14680629.2019.1579754.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85063780143&doi=10.1080%2f14680629.2019.1579754&partnerID=40&md5=2cbaedc4c69e7812c66f0726928532e2.

12. E. ŞENGÜN, et al. *The Effects of Compaction Methods and Mix Parameters on the Properties of Roller Compacted Concrete Mixtures.* 228(2019)10.1016/j.conbuildmat.2019.116807.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85071517180&doi=10.1016%2fj.conbuildmat.2019.116807&partnerID=40&md5=5ba910121f3a8965a2f14276bd316453.

13. C. CHHORN, et al. *Relationship between Compressive and Tensile Strengths of Roller-Compacted Concrete.* 53p. 215-23(2018)10.1016/j.jtte.2017.09.002.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85048318197&doi=10.1016%2fj.jtte.2017.09.002&partnerID=40&md5=7e850a60ecc19068c10a429618078e61.

14. M. RAO, et al. *Influence of Maximum Aggregate Sizes on the Performance of RCC.* 115p. 42-7(2016)10.1016/j.conbuildmat.2016.03.172.https://www.scopus.com/inward/record.uri?eid=2-s2.0-84962921610&doi=10.1016%2fj.conbuildmat.2016.03.172&partnerID=40&md5=457b00b7c2f962d84f50df9a39454baf.

15. M. ADAMU, et al. *Mechanical Properties and Performance of High Volume Fly Ash Roller Compacted Concrete Containing Crumb Rubber and Nano Silica.* (2018)https://www.scopus.com/inward/record.uri?eid=2-s2.0-85044468235&doi=10.1016%2fj.conbuildmat.2018.03.138&partnerID=40&md5=0a15a7cfd0fe25e9cc3d819a713ee0b3.

16. C. KHOURY, et al. *Mix Design of Roller Compacted Concrete Pavement using Steel Slag by-Products.* (2019)https://www.scopus.com/inward/record.uri?eid=2-s2.0-85063451148&doi=10.1061%2f9780784482124.040&partnerID=40&md5=d5265e771b57738c1d099bcbfdc6153b.

17. A. MARDANI-AGHABAGLOU and RAMYAR, K. *Mechanical Properties of High-Volume Fly Ash Roller Compacted Concrete Designed by Maximum Density Method.* 38p. 356-64(2013)10.1016/j.conbuildmat.2012.07.109.https://www.scopus.com/inward/record.uri?eid=2-s2.0-84866694511&doi=10.1016%2fj.conbuildmat.2012.07.109&partnerID=40&md5=b1e76bea898e823d2842791255686996.

18. A. YERRAMALA and GANESH BABU, K. *Transport Properties of High Volume Fly Ash Roller Compacted Concrete.* (2011)https://www.scopus.com/inward/record.uri?eid=2-s2.0-80054026528&doi=10.1016%2fj.cemconcomp.2011.07.010&partnerID=40&md5=a74103152bbad3552f4acf663af4480b.

19. P. TEJA ABHILASH, et al. *Variability in Compressive and Split Tensile Strength of Roller Compacted Concrete for Rigid Pavements.* 75(2022)10.1007/s41062-022-00898-6.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85135438877&doi=10.1007%2fs41062-022-00898-6&partnerID=40&md5=13bd4111432da097b6f2a8ee3c9c221e.

20. N. AMER, et al. *Using Gyratory Compaction to Investigate Density and Mechanical Properties of Roller-Compacted Concrete.* 18341p. 77-84(2003).

21. A.I. HUSEIN MALKAWI, et al. *A Comparative Study of Physical and Chemical Properties of Different Pozzolanic Materials used for Roller Compacted Concrete RCC Dams.* (2017)https://www.scopus.com/inward/record.uri?eid=2-s2.0-

85028061443&doi=10.1051%2fmatecconf%2f201712002025&partnerID=40&md5=09643203fb7140e233c777b79de12944.

22. S.W. LEE, et al. *Mechanical Performance and Field Application of Low Cement Based Concrete Under Compaction Energy.* 184p. 1053-62(2014)10.1007/s12205-014-0353-1.https://www.scopus.com/inward/record.uri?eid=2-s2.0-84899642442&doi=10.1007%2fs12205-014-0353-1&partnerID=40&md5=19943a5fea18073b336bef1fbe8339f5.

23. B.A.V. RAM KUMAR and RAMAKRISHNA, G. *Performance Evaluation of Sustainable Materials in Roller Compacted Concrete Pavements: A State of Art Review.* 71(2022)10.1007/s41024-022-00212-y.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85135182624&doi=10.1007%2fs41024-022-00212-y&partnerID=40&md5=0356a53ff8d0e940829aa2af6483bf93.

24. M. HASHEMI, et al. *The Effect of Superplasticizer Admixture on the Engineering Characteristics of Roller-Compacted Concrete Pavement.* 237p. 2432-47(2022)10.1080/10298436.2020.1858483.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85097819960&doi=10.1080%2f10298436.2020.1858483&partnerID=40&md5=2901ecabf1aa09212f48df964e28ec84.

25. A. KHEIRBEK, et al. *Experimental Study on the Physical and Mechanical Characteristics of Roller Compacted Concrete made with Recycled Aggregates.* 74(2022)10.3390/infrastructures7040054.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85128467735&doi=10.3390%2finfrastructures7040054&partnerID=40&md5=0751bb9a6e925c96b1eff1dbaaec313b.

26. M.K. MUSA and NASSRULLAH, H.M. *Road Construction by using Rolled Compacted Concrete.* 812p. 673-8(2019)10.35940/ijitee.L2783.1081219.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85074966721&doi=10.35940%2fijitee.L2783.1081219&partnerID=40&md5=f00e188b145b7d78eb7bfe00052106cf.

27. E. SENGUN, et al. *Strength and Fracture Properties of Roller Compacted Concrete (RCC) Prepared by an in-Situ Compaction Procedure.* 271(2021)10.1016/j.conbuildmat.2020.121563.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85096579439&doi=10.1016%2fj.conbuildmat.2020.121563&partnerID=40&md5=25b8adab2f8858db8c41fa57738be14e.

28. M. HASHEMI, et al. *The Effect of Coarse to Fine Aggregate Ratio on the Fresh and Hardened Properties of Roller-Compacted Concrete Pavement.* 169p. 553-66(2018)10.1016/j.conbuildmat.2018.02.216.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85042918025&doi=10.1016%2fj.conbuildmat.2018.02.216&partnerID=40&md5=d4daec53e647ad0050a269a057ffd29b.

29. H. ROOHOLAMINI, et al. *Effect of Electric Arc Furnace Steel Slag on the Mechanical and Fracture Properties of Roller-Compacted Concrete.* 211p. 88-98(2019)10.1016/j.conbuildmat.2019.03.223.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85063254370&doi=10.1016%2fj.conbuildmat.2019.03.223&partnerID=40&md5=dc15efd7b54c599bf0e3204bfd404221.

30. M. ADAMU, et al. *Durability Performance of High Volume Fly Ash Roller Compacted Concrete Pavement Containing Crumb Rubber and Nano Silica.*

(2020)https://www.scopus.com/inward/record.uri?eid=2-s2.0-85057265788&doi=10.1080%2f10298436.2018.1547825&partnerID=40&md5=af15ac459e7c71875d933111ec540266.

31. E. RAHMANI, et al. *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).* 253(2020)10.1016/j.conbuildmat.2020.119177.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85083345606&doi=10.1016%2fj.conbuildmat.2020.119177&partnerID=40&md5=c58cc47176836ec57c3bdcd5f3edfacb.

32. A. GARDUNO and MONTERO, M. *An Option for the use of Fly Ash on Roller Compacted Concrete Dams in Mexico.* (2010)https://www.scopus.com/inward/record.uri?eid=2-s2.0-84861035052&doi=10.1201%2fb10552-218&partnerID=40&md5=3718586064ad52896fad3a83f6f0feed.

33. Z. WU, et al. *Factors Affecting Air-Entrainment and Performance of Roller Compacted Concrete.* 259(2020)10.1016/j.conbuildmat.2020.120413.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85090041425&doi=10.1016%2fj.conbuildmat.2020.120413&partnerID=40&md5=138353cbeb2e5b08581485a64aa62696.

34. J. LAHUCIK and ROESLER, J. *Predicting Roller-Compacted Concrete Properties from Mixture Proportions.* (2017)https://www.scopus.com/inward/record.uri?eid=2-s2.0-85058504768&doi=10.1201%2f9781315100333-119&partnerID=40&md5=802bd16f562486e02ef64250667f0c5a.

35. S. KRISHNA RAO, et al. *Experimental Investigation on Pozzolanic Effect of Fly Ash in Roller Compacted Concrete Pavement using Manufactured Sand as Fine Aggregate.* (2015)https://www.scopus.com/inward/record.uri?eid=2-s2.0-84929847305&partnerID=40&md5=a908394a0c75447dded4ec0068bd5361.

36. A.A. RAMEZANIANPOUR, et al. *Mechanical Properties and Durability of Roller Compacted Concrete Pavements in Cold Regions.* 146p. 260-6(2017)10.1016/j.conbuildmat.2017.04.099.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85018513379&doi=10.1016%2fj.conbuildmat.2017.04.099&partnerID=40&md5=150f6e928f404e43d504b28b2759dbc2.

37. M.N.-. LAM, et al. *Compressive Strength and Durability Properties of Roller-Compacted Concrete Pavement Containing Electric Arc Furnace Slag Aggregate and Fly Ash.* 191p. 912-22(2018)10.1016/j.conbuildmat.2018.10.080.https://www.scopus.com/inward/record.uri?eid=2-s2.0-85054923166&doi=10.1016%2fj.conbuildmat.2018.10.080&partnerID=40&md5=109e402e84e50fdc63a889116b7e0d8a.

38. B.W. XU and SHI, H.S. *Correlations among Mechanical Properties of Steel Fiber Reinforced Concrete.* 2312p. 3468-74(2009)https://doi.org/10.1016/j.conbuildmat.2009.08.017.https://www.scopus.com/inward/record.uri?eid=2-s2.0-70349267497&doi=10.1016%2fj.conbuildmat.2009.08.017&partnerID=40&md5=08528cf0b0a55fe32b67161d9258fd04.

39. M.J. SETZER, et al. *CDF test—Test Method for the Freeze-Thaw Resistance of Concrete-Tests with Sodium Chloride Solution (CDF) Recommendation.* 299p. 523-8(1996)https://doi.org/10.1007/BF02485951.

40. A. MARDANI-AGHABAGLOU, et al. *Freeze-Thaw Resistance and Transport Properties of High-Volume Fly Ash Roller Compacted Concrete Designed by Maximum Density Method.* 371p. 259-66(2013)10.1016/j.cemconcomp.2013.01.009.https://www.scopus.com/inward/record.uri?eid=2-s2.0-84874650045&doi=10.1016%2fj.cemconcomp.2013.01.009&partnerID=40&md5=9b41187e56709d43627974449bd39fbb.

41. DAUKŠYS, Mindaugas, et al. *The Assessment of Prediction Methodology of Concrete Freezing and Thawing Resistance*. Materials Science, 2012, 18.4: 403-409.