Lecture Notes in Civil Engineering

Han Ay Lie · Monty Sutrisna ·
Joewono Prasetijo ·
Bonaventura H.W. Hadikusumo ·
Leksmono Suryo Putranto *Editors*

Proceedings of the Second International Conference of Construction, Infrastructure, and Materials

ICCIM 2021, 26 July 2021, Jakarta, Indonesia

Springer

Lecture Notes in Civil Engineering

Volume 216

Lecture Notes in Civil Engineering (LNCE) publishes the latest developments in Civil Engineering—quickly, informally and in top quality. Though original research reported in proceedings and post-proceedings represents the core of LNCE, edited volumes of exceptionally high quality and interest may also be considered for publication. Volumes published in LNCE embrace all aspects and subfields of, as well as new challenges in, Civil Engineering. Topics in the series include:

- Construction and Structural Mechanics
- Building Materials
- Concrete, Steel and Timber Structures
- Geotechnical Engineering
- Earthquake Engineering
- Coastal Engineering
- Ocean and Offshore Engineering; Ships and Floating Structures
- Hydraulics, Hydrology and Water Resources Engineering
- Environmental Engineering and Sustainability
- Structural Health and Monitoring
- Surveying and Geographical Information Systems
- Indoor Environments
- Transportation and Traffic
- Risk Analysis
- Safety and Security

To submit a proposal or request further information, please contact the appropriate Springer Editor:

– Pierpaolo Riva at pierpaolo.riva@springer.com (Europe and Americas);
– Swati Meherishi at swati.meherishi@springer.com (Asia - except China, and Australia, New Zealand);
– Wayne Hu at wayne.hu@springer.com (China).

All books in the series now indexed by Scopus and EI Compendex database!

More information about this series at https://link.springer.com/bookseries/15087

Han Ay Lie · Monty Sutrisna ·
Joewono Prasetijo ·
Bonaventura H.W. Hadikusumo ·
Leksmono Suryo Putranto
Editors

Proceedings of the Second International Conference of Construction, Infrastructure, and Materials

ICCIM 2021, 26 July 2021, Jakarta, Indonesia

Springer

Editors
Han Ay Lie
Department of Civil Engineering
Diponegoro University
Semarang, Indonesia

Monty Sutrisna
School of Built Environment
Massey University
Auckland, New Zealand

Joewono Prasetijo
Department of Transportation Engineering Technology
Universiti Tun Hussein Onn Malaysia
Panchor, Malaysia

Bonaventura H.W. Hadikusumo
Department of Construction, Engineering and Infrastructure Management
Asian Institute of Technology
Klong Luang, Thailand

Leksmono Suryo Putranto
Civil Engineering Department
Universitas Tarumanagara
Jakarta Barat, Indonesia

ISSN 2366-2557 ISSN 2366-2565 (electronic)
Lecture Notes in Civil Engineering
ISBN 978-981-16-7948-3 ISBN 978-981-16-7949-0 (eBook)
https://doi.org/10.1007/978-981-16-7949-0

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Organization

Steering Committee

Prof. Han Ay Lie, Diponegoro University, Indonesia
Prof. Buntara Sthenly Gan, Nihon University, Japan
Dr. Najid, Universitas Tarumanagara, Indonesia
Dr. Widodo Kushartomo, Universitas Tarumanagara, Indonesia

International Scientific Committee

Prof. Leksmono Suryo Putranto, Universitas Tarumanagara, Indonesia
Prof. Buntara Sthenly Gan, Nihon University, Japan
Dr. Dimas Bayu Endrayana Dharmowijoyo, Universiti Teknologi Petronas, Malaysia
Dr. Bashar S. Mohammed, Universiti Teknologi Petronas, Malaysia
Dr. Andri Setiawan, Ecole Polytechnique Federale de Lausanne, Switzerland
Dr. Fadhilah Muslim, Universitas Indonesia, Indonesia; Technical University of Munich, Germany
Prof. Han Ay Lie, Universitas Diponegoro, Indonesia
Prof. Chaidir Anwar Makarim, Universitas Tarumanagara, Indonesia
Prof. Dewa Made Priyantha Wedagama, Universitas Udayana, Indonesia
Prof. Sofyan M. Saleh, Universitas Syiah Kuala, Indonesia
Prof. Eng. Joni Arliansyah, Universitas Sriwijaya, Indonesia
Prof. Sakti Adji Adisasmita, Universitas Hassanuddin, Indonesia
Prof. Siti Malkhamah, Universitas Gadjah Mada, Indonesia
Prof. Krishna Mochtar, Institut Teknologi Indonesia, Indonesia

Prof. Ade Sjafruddin, Institut Teknologi Bandung, Indonesia
Prof. Ludfi Djakfar, Universitas Brawijaya, Indonesia
Prof. Wimpy Santosa, Universitas Parahyangan, Indonesia
Prof. Antonius, Universitas Islam Sultan Agung, Indonesia
Prof. Erika Buchari, Universitas Sriwijaya, Indonesia
Prof. Ria Asih Aryani Soemitro, Institut Teknologi Sepuluh November, Indonesia
Prof. I Nyoman Arya Thanaya, Universitas Udayana, Indonesia
Dr. Hermawan, Universitas Katolik Soegijapranata, Indonesia
Dr. Maria Wahyuni, Universitas Katolik Soegijapranata, Indonesia
Dr. Djoko Suwarno, Universitas Katolik Soegijapranata, Indonesia
Dr. Bayu Martanto Adji, Universitas Andalas, Indonesia
Dr. Aine Kusumawati, Institut Teknologi Bandung, Indonesia
Dr. Bagus Hario Setiadji, Universitas Diponegoro, Indonesia
Dr. Basuki Anondho, Universitas Tarumanagara, Indonesia
Dr. Widodo Kushartomo, Universitas Tarumanagara, Indonesia
Dr. Najid, Universitas Tarumangara, Indonesia
Dr. Dewanti Marsoyo, Universitas Gadjah Mada, Indonesia
Dr. Wati A. Pranoto, Universitas Tarumanagara, Indonesia
Dr. Noor Mahmudah, Universitas Muhammadiyah Yogyakarta, Indonesia
Dr. Eng. Muhammad Isran Ramli, Universitas Hassanuddin, Indonesia
Dr. Eng. Imam Muthohar, Universitas Gadjah Mada, Indonesia
Dr. Achmad Wicaksono, Universitas Brawijaya, Indonesia
Dr. Caroline A. Sutandi, Universitas Parahyangan, Indonesia
Dr. Hera Widyastuti, Institut Teknologi Sepuluh November, Indonesia
Dr. R. Sony Sulaksono Wibowo, Institut Teknologi Bandung, Indonesia
Dr. Resdiansyah, Universitas Pembangunan Jaya, Indonesia
Dr. Yosritzal, Universitas Andalas, Indonesia
Dr. M. Asad Abdurrahman, Unversitas Hassanuddin, Indonesia
Dr. Eng. M. Zudhy Irawan, Universitas Gadjah Mada, Indonesia
Dr. Ir. Hitapriya Suprayitno, M.Eng., Institut Teknologi Sepuluh November, Indonesia
Dr. Ani Hairani, Universitas Muhammadiyah Yogyakarta, Indonesia
Dr. Hendy Setiawan, Universitas Gadjah Mada, Indonesia
Dr. Alfred Jonathan Susilo, Universitas Tarumanagara, Indonesia
Dr. Aksan Kawanda, Universitas Trisakti, Indonesia
Dr. Nurul Fajar Januriyadi, Universitas Pertamina, Indonesia
Dr. Neil Andika, Universitas Gadjah Mada, Indonesia
Dr. Faizal Immaddudin Wira Rohmat, Institut Teknologi Bandung, Indonesia
Dr. Usman Wijaya, Universitas Kristen Krida Wacana, Indonesia
Dr. Leni Sagita Riantini, Universitas Indonesia, Indonesia
Dr. Hendrik Sulistio, Universitas Tarumanagara, Indonesia
Dr. Jane Sekarsari, Universitas Trisakti, Indonesia

Local Organizing Committee

Chairman
Prof. Chaidir Anwar Makarim, Universitas Tarumanagara, Indonesia

Vice Chairwoman
Anissa Noor Tajudin, Universitas Tarumanagara, Indonesia

Members
Prof. Leksmono Suryo Putranto, Universitas Tarumanagara, Indonesia
Yenny Untari, Universitas Tarumanagara, Indonesia
Dewi Linggasari, Universitas Tarumanagara, Indonesia
Vittorio Kurniawan, Universitas Tarumanagara, Indonesia
Aniek Prihatiningsih, Universitas Tarumanagara, Indonesia
Arif Sandjaya, Universitas Tarumanagara, Indonesia
Abdul Roji, Universitas Tarumanagara, Indonesia
Slamet Riyadi, Universitas Tarumanagara, Indonesia
Daniel Christianto, Universitas Tarumanagara, Indonesia
Arianti Sutandi, Universitas Tarumanagara, Indonesia
Ni Luh Putu Shinta Eka Setyarini, Universitas Tarumanagara, Indonesia
Anugerah Tiffanyputri, Universitas Tarumanagara, Indonesia
Matthew Ephraim, Universitas Tarumanagara, Indonesia
Saskia Calysta Zetira, Universitas Tarumanagara, Indonesia
Channy Saka, Universitas Tarumanagara, Indonesia
Jessica Clarita, Universitas Tarumanagara, Indonesia
Prem Singh, Universitas Tarumanagara, Indonesia
Federick Luanga, Universitas Tarumanagara, Indonesia

Preface

This new volume of Lecture Notes in Civil Engineering contains the proceedings of the Second International Conference of Construction, Infrastructure, and Materials (ICCIM 2021). This book presents the latest development in civil engineering on a global scale. It highlights the conference scopes, such as Structural Engineering, Construction Materials, Geotechnical Engineering, Transportation System and Engineering, Constructions Management, Water Resources Engineering, and Infrastructure Development. The 55 articles published in this book went through peer-review processes double-blindly and plagiarism check. Manuscript assessments by the expert reviewers were based on the organizer's technical criteria, including technical criteria, quality criteria, and presentation criteria.

The Second International Conference of Construction, Infrastructure, and Materials (ICCIM 2021) was hosted by the Civil Engineering Undergraduate Study Program of Universitas Tarumanagara, Indonesia, on 26 July 2021. The conference brought together national and international experts to share their researches, knowledge, and experiences. ICCIM 2021 carried the theme "Research and Technology in Civil Engineering to Enhance the Sustainability of the Built Environment".

Due to the global COVID-19 pandemic, which has impacted all activities globally, ICCIM 2021 was held as an online conference. ICCIM 2021 online conference aimed to capture a broader range of participants. The Conference was also expected to facilitate researchers, practitioners, and students in their respective fields of expertise to share information and exchange ideas about the current state of civil engineering development.

ICCIM 2021 was supported by Massey University, New Zealand; Universiti Tun Hussein Onn Malaysia, Malaysia; Nihon University, Japan; fib Indonesia; Diponegoro University, Indonesia; Soegijapranata Catholic University, Indonesia; Universitas Sebelas Maret, Indonesia; and Universitas Atma Jaya Yogyakarta, Indonesia.

ICCIM 2021 has received papers from various countries, such as Indonesia, Japan, Thailand, the United Kingdom, the United States of America, the

Philippines, India, Nigeria, and Bangladesh. More than 600 researchers, practitioners, and students from all over the world registered to attend the Conference.

We are likewise grateful to the keynote speakers for bringing the exciting topics to ICCIM 2021: Prof. Roesdiman Soegiarso (Universitas Tarumanagara, Indonesia); Prof. Monty Sutrisna (Massey University, New Zealand); Dr.-Ing. Joewono Prasetijo (Universiti Tun Hussein Onn Malaysia, Malaysia); and Dr. Tam Chat Tim (National University of Singapore, Singapore).

We would also like to extend our appreciation to the supporting institutions. Secondly, thank you to the sponsors for the utmost support and kind contribution: PT. Waskita Karya (Persero) Tbk, PT. Pamapersada Nusantara, and PT. Bank Negara Indonesia Tbk.

Many people have worked very hard for the organization of this Conference. Special thanks are needed to the Organizing Committee, Steering Committee, Editorial Board, and Scientific Committee. All of whom have generously worked to make this Conference rich in content and pleasant for the attendees. We would also like to thank all the authors who have contributed to the success of this Conference.

Semarang, Indonesia — Han Ay Lie
Auckland, New Zealand — Monty Sutrisna
Panchor, Malaysia — Joewono Prasetijo
Klong Luang, Thailand — Bonaventura H. W. Hadikusumo
Jakarta Barat, Indonesia — Leksmono Suryo Putranto

Contents

About the Editors

Prof. Dr. Han Ay Lie is working as Professor in the Department of Civil Engineering, Diponegoro University, Indonesia. At present, she is also Chairwoman of the International Federation of Structural Concrete Indonesia (fib-Indonesia). She has also taken the role of external examiner and is Advisor for many national and international universities. Her research interests include graded concrete, fibre-reinforced plastics for concrete, retrofitting and external reinforcing, modeling, and finite element analysis.

Prof. Dr. Monty Sutrisna is Professor of Construction and Project Management at Massey University, New Zealand. He is currently Head of the School of Built Environment at the same institution. His expertise includes Construction and Engineering Management, Construction Productivity, Construction Procurement and Contracts, Construction IT and other Advanced Technologies applied in Construction, Construction Project Management, Decision Making Modelling/Support, and Knowledge-Based Systems and Artificial Intelligence.

Dr.-Ing. Joewono Prasetijo teaches in the Department of Transportation Engineering Technology at Universiti Tun Hussein Onn Malaysia (UTHM), Malaysia. He has been Head of the Industry Center of Excellence—Railway (ICoE Rel) of Universiti Tun Hussein Onn Malaysia (UTHM) since 2020. He is professionally certified as Permanent Way Inspection: CO2 Track Maintenance Works (2019) and Professional Technologist (2020). His research interests include land transportation engineering, transportation safety, and rail technology.

Prof. Dr. Bonaventura H. W. Hadikusumo is Professor at the School of Engineering and Technology, Asian Institute of Technology, Thailand. His key expertise and interests encompass the area of safety management, system dynamics, project visualization, intelligent agent system, knowledge management tools, IT applications like building information modeling (BIM) and simulation in construction site improvement, and Web-based project management.

Prof. Dr. Leksmono Suryo Putranto is Professor in the Department of Civil Engineering, Universitas Tarumangara, Indonesia. He has been actively involved in a leading role in research conferences as organizing and scientific committees. He currently acts as Chief of Research and Development Commission in Jakarta Transportation Council. Social psychology, safety engineering, and transportation engineering are some of his areas of expertise and interest.

Effect of Cement–Water Ratio on the Mechanical Properties of Reactive Powder Concrete with Marble Powder as Constituent Materials

Widodo Kushartomo, Henny Wiyanto, and Daniel Christianto

Abstract The main principle of developing reactive powder concrete is to improve the microstructure by compacting density and increasing toughness. To achieve this principle very high-grade cement is used together with pozzolanic materials. The research was conducted to study the effect of the water-cement ratio on the mechanical properties of reactive powder concrete with marble powder as constituent materials. Trial mixes were prepared using cement, sand, silica fume, marble powder, and super-plasticizer. A mix ratio of 1.0:1.1:0.2:0.1:0.03 was adopted with water-cement ratio of 0.18, 0.20, and 0.22. Concrete cylinder of size ∅10 cm × 20 cm and the concrete beam of size 10 cm × 10 cm × 35 cm were cast and cured in steam curing at 95 °C for 4 h and tested to study the compressive strength, modulus elasticity, splitting strength, and flexural strength in relation to the water-cement ratio. The results indicate that reduced water-cement ratio from 0.22 to 0.18 increases the compressive strength, modulus elasticity, splitting strength, and flexural strength. Using a lower water-cement ratio for the mixing process is difficult to handle, so this research recommended a 0.20 water-cement ratio to produce reactive powder concrete with optimum mechanical properties.

Keywords Concrete · Water-cement ratio · Mechanical properties · Strength · Marble powder

1 Introduction

The low water-cement ratio (w/c ratio) impacts concrete's high strength and durability, as shown in Fig. 1 [1], but a lower water-cement ratio resulted in difficulties in mixing and placing. Workability can be resolve by using admixture such as super-plasticizer.

W. Kushartomo (✉) · H. Wiyanto · D. Christianto
Department of Civil Engineering, Faculty of Engineering, Universitas Tarumanagara, Jakarta 11440, Indonesia
e-mail: widodo@untar.ac.id

H. A. Lie et al. (eds.), *Proceedings of the Second International Conference of Construction, Infrastructure, and Materials*, Lecture Notes in Civil Engineering 216,
https://doi.org/10.1007/978-981-16-7949-0_16

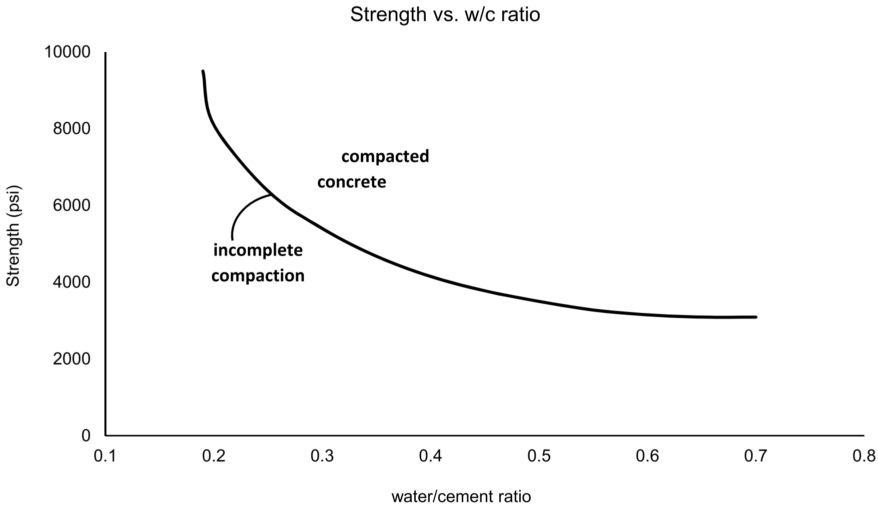

Fig. 1 Correlation water-cement ratio with compressive strength for normal concrete [1]

However, a mixture with a water-cement ratio between 0.18 and 0.22 will not mix well and is not plastic enough to be poured into the formwork. The presence of water is technically required for the hydration reaction to occur in cement. Water-cement ratios between 0.45 and 0.60 are more often used in regular concrete. For high-strength concrete, use a low water-cement ratio plus a plasticizer to increase workability. Excess water in a mixture causes segregation of the coarse aggregate to the cement paste. Water that is not used in the hydration reaction, when the concrete hardens, will leave a trail in the form of pores, whether the pores are open or closed. The pores that are formed will reduce the strength of concrete. A concrete mix with too much water can also cause shrinkage as the concrete dries and cracks concrete corners. The shrinkage in the end also reduces the strength of the concrete [1].

Reactive powder concrete (RPC) is categorized as ultra-high-performance concrete (UHPC). The term reactive powder means that all powder components in RPC can react chemically. However, the word concrete is preferred over mortar to describe UHPC by including steel fiber as one of its compositions. The use of steel fiber aims to increase its ductility. However, the RPC development does not include steel fiber as one of the development objects. The microstructural modification method is chosen as an effort to develop RPC with very high compressive strength, very high durability, and very high toughness. The principles of RPC development are as follows:

- Develop microstructure and eliminate coarse aggregate
- Enhance particle packing
- Increase toughness.

RPC's performance is associated with a low water-cement ratio, admixture, fineness of quartz sand, super-plasticizer, and small-sized steel fiber. Due to its excellent mechanical properties, RPC is exhibited in various applications in the construction field, such as bridge structures, high rise buildings, nuclear waste structures, marine structures, precast applications, and as an effective repair material [2].

To achieve the perfect density and homogeneity of the matrix to form pores as minimal as possible, the RPC must be related to the aggregate gradation between 150 and 600 µm. It is not recommended to use fine aggregate with a grain size below 150 µm to produce an optimum granular packing [2].

The function of marble powder is as a paste-aggregate interface filler, which significantly reduces the void of RPC, which will cause the pores to break and result in very low permeability, no cracks, and thus increase the strength. An Improvement of the RPC microstructure can be made by increasing the curing temperature, which causes the C-S-H (Calcium Silicate Hydrate) chain to be longer due to the high hydration of the cement. The high curing temperature also causes an increasing pozzolanic activity from marble powder to reactive silica, thus encouraging the pozzolanic reaction and producing more CSH gel [1, 2].

The addition of marble powder to the RPC can increase the compressive strength by up to 20%. The amount of marble powder used in the manufacture of RPC should be 10–30% of the amount of cement.

RPC quality can be achieved if the ratio of the amount of water-cement ranges from 0.18 to 0.22. The low water-cement ratio will reduce porosity on RPC and increase the compact density. Increasing compact density has a positive impact on decreasing porosity in the mortar.

The primary purpose of the RPC mix design development process is to get the best mechanical properties. There are two basic parameters in achieving the best mechanical properties:

- Appropriate selection of RPC constituent materials
- Water-cement ratio.

Packing density for RPC can be achieved by adjusting all grain sizes used, such as fine aggregate, silica fume, and quartz powder. Temperature and maintenance pressure also significantly affect the mechanical properties of RPC. Steam maintenance at high temperature and pressure can accelerate the hydration reaction and force a chemical reaction to occur in all RPC ingredients.

This study aims to develop the mechanical properties of RPC with the water-cement ratio as an influencing component.

2 Methodology

The materials used in this investigation are cement, sand, silica fume, marble powder, and super-plasticizer, and water. Experimental Test Procedures Mix proportions of 1.0:1.1:0.25:0.1:0.03 were adopted with a water-cement ratio of 0.22, 0.20, and 0.18 was determined using cement, fine aggregates, silica fume, marble powder, and super-plasticizer, respectively as shown in Table 1. The cylinder ∅10 cm × 20 cm and the beam of size 10 cm × 10 cm × 35 cm molds of concrete were oiled to ease the de-molding process late. After 24 h of sitting time, the samples were de-molded and placed in a curing water tank for 7. After that, the samples were cast and cured in steam curing at 95 °C for 4 h. All samples were tested to study the compressive strength, splitting strength, and flexural strength in relation to the water-cement ratio at 28 age.

3 Result and Discussion

The mechanical properties of reactive powder concrete (RPC) as w/c ratio functions results are presented in Fig. 2. The strength value of mechanical properties RPC will be increased if the w/c ratio reduces. The highest value of mechanical properties reached the lowest w/c ratio, which corresponds to an improvement of microstructure, particle packing, and cementitious constituents.

3.1 Improvement of Microstructure

RPC's mechanical properties and durability are influenced by the bond between the cement paste and aggregate, known as the Interfacial Transition Zone (ITZ). Observing the microstructure in the ITZ area shows the pattern of micro cracks and

Table 1 Materials composition

Materials	ρ (kg/m^3)	w/c = 0.22		w/c = 0.20		w/c = 0.18	
		Ratio	Wight (kg)	Ratio	Wight (kg)	Ratio	Wight (kg)
Cement	3150.0	1.00	880.00	1.00	896.00	1.00	912.00
Water	1000.0	0.22	193.60	0.20	179.20	0.18	164.16
Micro silica	2200.0	0.25	220.00	0.25	224.00	0.25	228.00
Sand	2617.8	1.10	968.00	1.10	985.60	1.10	1003.20
Marble powder	2563.0	0.10	88.00	0.10	89.60	0.10	91.20
Superplasticizer	1150.0	0.03	26.40	0.03	26.88	0.03	27.36

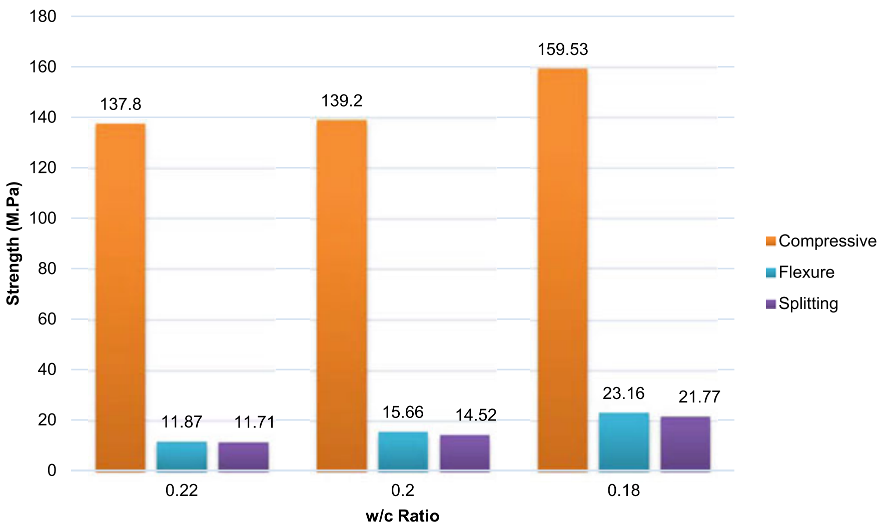

Fig. 2 Mechanical properties of RPC as w/c ratio functions

the occurrence of crack propagation. The stress–strain graph for aggregate, concrete, and cement paste is shown in Fig. 3 [2].

Figure 3 shows the elastic and brittle behavior of cement paste and aggregate, while concrete shows ductile behavior. This is related to the development of the rift in the ITZ area. RPC is designed by developing microstructures, such as compact density using pozzolanic materials and admixtures that increase its homogeneity. The addition of fine particles such as marble powder can increase the packing density, increasing the density in the ITZ region without noticeable pores, as shown in Fig. 4. The low water-cement ratio significantly impacts the decrease in porosity, as shown in Fig. 4.

As shown in Fig. 4, ettringite is formed between the material that is not entirely hydrated and the C-S-H gel. The main hydration products (C-S-H gel) were homogeneous, $Ca(OH)_2$ was not found, and ettringite was formed [1, 2].

The microstructure of RPC depends on the conditions of heat treatment behavior. This is because the treatment temperature can change the microstructure of ITZ and the activity of pozzolanic materials.

The real improvement in improving the microstructure of RPC as well as distinguishing RPC from other classic high-performance concrete HPC is the removal of coarse aggregate and replacing it with quartz sand to increase bond strength within the matrix, increase homogeneity, reduce the effect of heterogeneity of microstructure which minimizes internal defects of the material such as voids and microcrack [2].

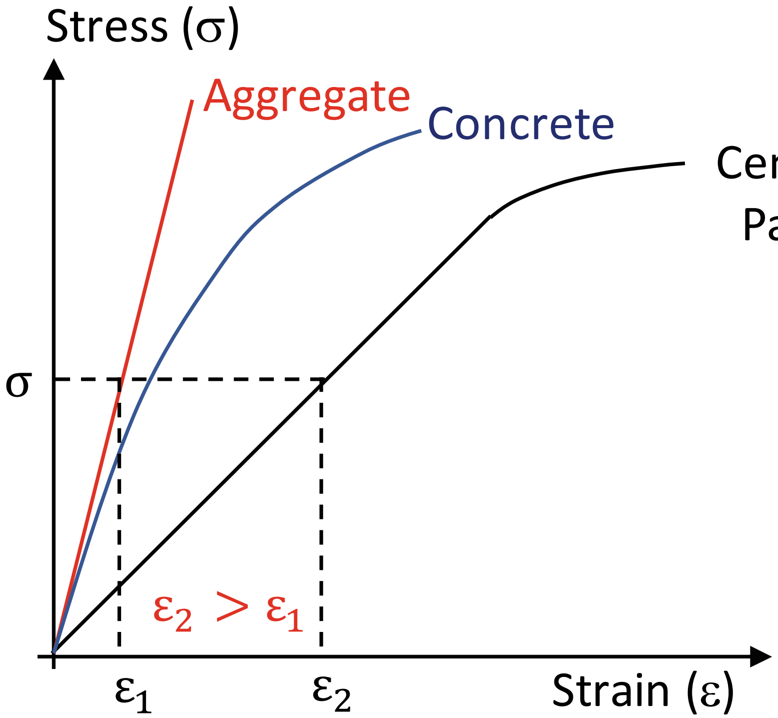

Fig. 3 Comparative stress–strain curves for aggregate, paste, and concrete [2]

3.2 Particle Packing

The primary purpose of applying the packing density model is to obtain high mechanical strength. This can be achieved by combining the appropriate size and proportion of small particles to reduce the voids formed. In this case, the performance of RPC is influenced by the size and percentage of pores formed, which affects the type and a density level of the constituent components. The finer particles fill the voids found between the cement and the aggregate particles. This causes efficient compaction of the voids between cement grains so that the overall performance of the concrete mix increases significantly [2–4].

The performance of RPC is enhanced by incorporating powder into the mix, which is the opposite of ordinary concrete which is highly affected by these fine materials. This powder creates a large surface area which requires high amounts of C-S-H gel. The high cement content in the RPC anticipates the formation of large C-S-H gels and increases the powder's surface area, thereby increasing the packing density [1, 2].

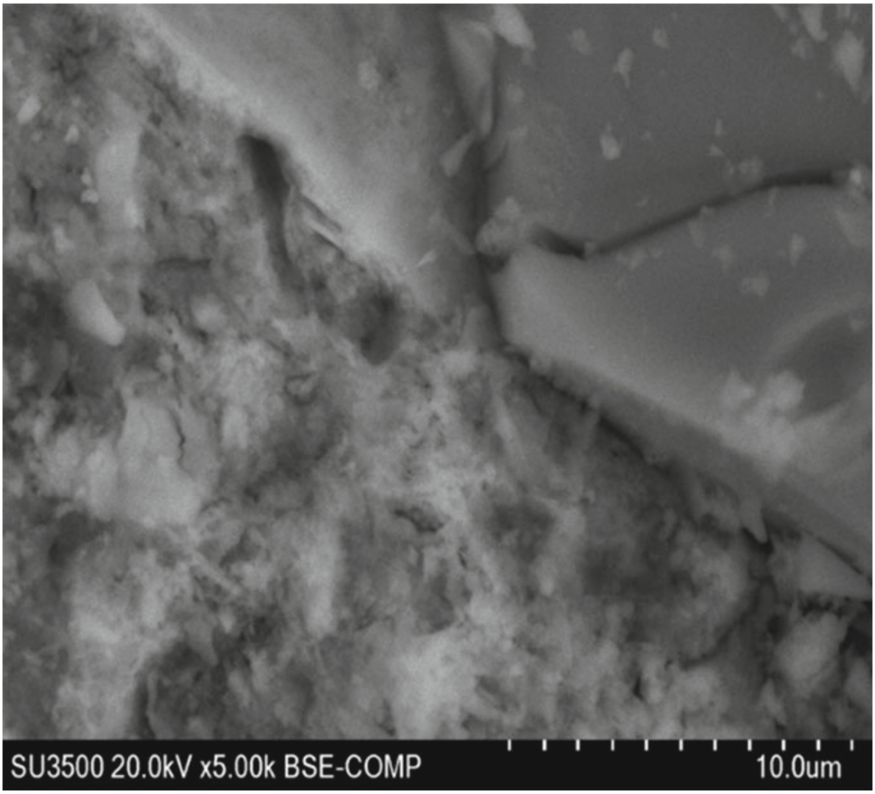

Fig. 4 Scanning electron microscope (SEM) of RPC, compacting interfacial transition zone with low w/c ratio

Ideally, the gradation curve and filling properties of powder materials such as cement, silica fume, quartz sand, and marble powder are the main concepts of the packing density approach, as shown in Fig. 5.

Some of the cement grains remain hydrated in the RPC mixture due to the low moisture content. Cement granules play a crucial role in the packing density of RPC because the grain size is between the sizes of silica fume and marble powder, thus helping in the process of filling pores [2, 4, 5].

The distance between the particles is filled with finer grains so that the density becomes better, as shown in Fig. 4. Using the principle of granular packing of cementations materials in RPC, capillary porosity in RPC is significantly reduced.

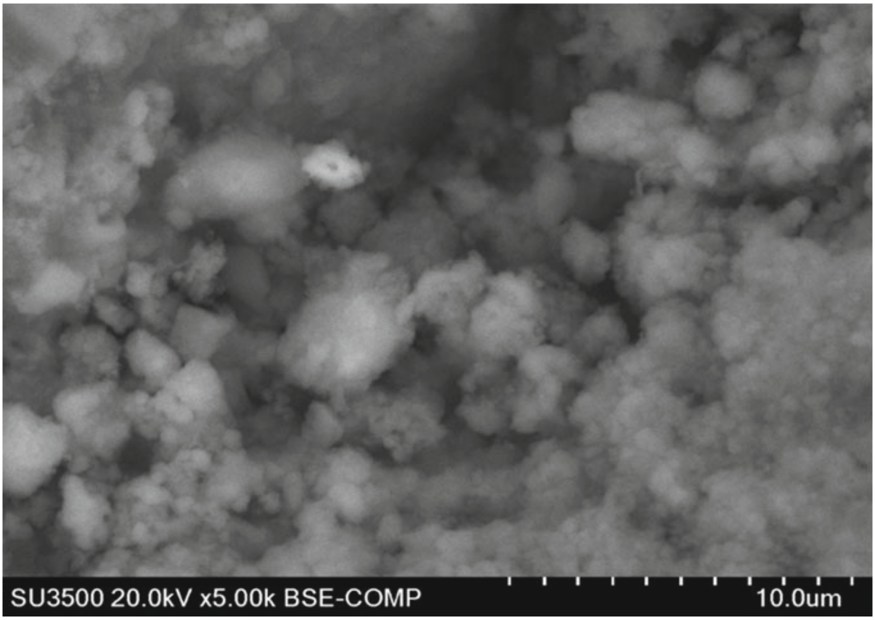

Fig. 5 Scanning electron microscope (SEM) of RPC, particle packing

3.3 Cementitious Constituents

The binder in RPC is divided into two materials, namely cement and pozzolan. The most used pozzolanic material is silica fume.

The cement and pozzolan used in the manufacture of RPC can be anything because there are no special requirements for the type of cement and pozzolan. The cement that is often used is cement with a low heat of hydration, considering that the quantity used is very high, namely type II cement. In the selection of cement, the cement grain size is also a consideration. Using cement with a high level of fineness will consume large amounts of water. The low water-cement ratio and the fine grain size of cement in RPC impact the mortar's performance factor, so caution is needed to use cement dosage. The dosage of cement commonly used in RPC ranges from about 700–1000 kg/m^3 to achieve ultra-high strength with very low moisture content. High cement content is vital to increase the formation of C-S–H gel to cause the compaction of particles in fine grains. Incomplete hydration of cement in RPC causes a lot of free cement granules. These grains play an essential role in the granular packing in RPC [1, 2, 6].

The use of enormous amounts of cement in RPC has many disadvantages to the environment, cost, and concrete behavior when it hardens. A high temperature of hydration, shrinkage, and dimensional stability are problems that often arise in using a lot of cement. Mineral admixtures such as silica fume can be an excellent alternative to reduce the adverse effects of using high cement content in RPC.

Improvement of concrete performance through the packing density effect activates a pozzolanic reaction. It accelerates the cement hydration process, which increases the formation of calcium silicate hydrate (C-S–H) and its derivatives. In terms of mechanics and durability, the advantages obtained from combining steel fiber and pozzolanic materials in RPC are high tensile strength, high flexural strength, high compressive strength, low permeability, high resistance to chemical attack (acid, nitric, chloride, and sulfate), high abrasion resistance, toughness, excellent durability [1, 2, 4].

4 Conclusions

1. The mechanical properties of RPC are determined mainly by the water-cement ratio and the components used. The smaller the value of the water-cement ratio, the greater the value of the mechanical strength of the RPC. Likewise, the finer the grain of the components used, the higher the value of the RPC mechanical strength.
2. Improvement of microstructure, removing coarse aggregate, adjusting grain size are the basic principles in the manufacture of RPC to improve its mechanical properties.
3. RPC requires high cement content, and pozzolanic materials must be used to obtain the required reactivity.
4. The enhancement in compressive strength can reaches when using marble powder.

References

1. Mindess S, Young JF (2002) Concrete. Prentice Hall, New Jersey
2. Mayhoub OA, Nasr ESAR, Ali YA, Kohail M (2021) The influence of ingredients on the properties of reactive powder concrete: a review. Ain Shams Eng J 12(1):145–158. https://doi.org/10.1016/J.ASEJ.2020.07.016
3. Kim YY, Lee KM, Bang JW, Kwon SJ (2014) Effect of W/C ratio on durability and porosity in cement mortar with constant cement amount. Adv Mater Sci Eng 2014. https://doi.org/10.1155/2014/273460
4. Apebo NS, Shiwua AJ (2013) Effect of water-cement ratio on the compressive strength of gravel—crushed over burnt bricks concrete. Civ Environ Res 3:74–81
5. Hiremath PN, Yaragal SC (2017) Effect of different curing regimes and durations on early strength development of reactive powder concrete. Constr Build Mater 154:72–87. https://doi.org/10.1016/J.CONBUILDMAT.2017.07.181
6. Al-Tikrite A, Hadi MNS (2017) Mechanical properties of reactive powder concrete containing industrial and waste steel fibres at different ratios under compression. Constr Build Mater 154:1024–1034. https://doi.org/10.1016/J.CONBUILDMAT.2017.08.024