UDK 620.1:67.017:691.32:666.363:691.214.8
Original scientific article/Izvirni znanstveni članek

ISSN 1580-2949
MTAEC9, 55(4)517(2021)

INFLUENCE OF QUARTZ SAND AND MARBLE-SLUDGE POWDER AS REPLACEMENTS FOR FINE AGGREGATE ON THE MECHANICAL PROPERTIES OF HIGH-STRENGTH SELF-COMPACTING CONCRETE

VPLIV ZAMENJAVE DROBNEGA KAMNITEGA AGREGATA S KREMENOVIM PESKOM IN PRAHOM IZ MARMORNE PULPE NA MEHANSKE LASTNOSTI VISOKO TRDNEGA SAMO-ZGOŠČEVALNEGA BETONA

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Prejem rokopisa – received: 2020-03-17; sprejem za objavo – accepted for publication: 2021-03-30

doi:10.17222/mit.2021.065

High-strength self-compacting concrete (HSSCC) is widely used as an eco-effective structure that is more durable than traditional cement that is more prone to demolitions and damage. One of today's notable innovations is self-compacting concrete (SCC). The variety of materials and the utilization of siphons encourage the concrete's use, which is significant. The worries about complex pieces are understandable due to the ease, with which precarious projecting zones are formed. This article presents high-strength self-compacting concrete, including quartz sand (QS) and marble-sludge powder (MSP) used as a partial replacement of fine aggregate (M sand). The substitution impact of QS and MSP on the strength of HSSCC is investigated. Further, V-funnel, L-box, slump flow, J-ring and slump cone are used to investigate the chemical, physical and mechanical properties such as splitting tensile strength, compressive strength, bond strength and flexural strength. The replacement of fine aggregate with 15 % of marble-sludge powder and 45 % of quartz sand (HSSCC concrete) gives an unprecedented outcome in the form of solidity and consistency. The findings show that the HSSCC 9 mix exhibits the compressive strength, splitting tensile strength, flexural strength and, more noteworthy, bond strength of 82.25 MPa, 8.10 MPa, 27.10 MPa and 11.89 MPa, respectively.

Keywords: high-strength self-compacting concrete, mechanical property, quartz sand, marble-sludge powder

Uporaba samozgoščevalnega betona z visoko trdnostjo je v primerjavi s konvencionalnim betonom primernejša, saj gre za ekološko in trajnostno ugodnejši material, izdelke iz njega pa je tudi lažje fiksirati in odstraniti. Njegova glavna prednost je, da se sam zgoščuje oziroma kompaktira (HSSCC; High Strength Self-compacting concrete). Avtorja tega članka je za razvoj in povečanje hitrosti izvajanja projekta spodbudila možnost izbire različnih materialov in njihova uporaba za izdelavo sifonov in podzemnih kanalov, pri katerih je pomemben njihov transport in montaža. V članku avtorja predstavljata izdelavo samozgoščevalnega betona z visoko trdnostjo, v katerem so delno nadomestili fini agregat (M pesek) s kremenovim peskom (QS) in prahom marmorne pulpe (MSP). Ugotavljajo, da je zamenjava materialov vplivala na mehansko trdnost izdelanega betona. Prepoznavali so kemijske, fizikalne in mehanske lastnosti (kot so cepilna, vezivna, upogibna in tlačna trdnost) različnih vrst oblikovancev; kot so kanali V oblike, škatle v obliki L, odtočni kanali, konusi in J obroči. Zamenjava finega agregatnega peska s 15 % prahu marmorne pulpe in 45 % kremenovega peska je nepričakovano izboljšala kompaktnost in konsistenco naštetih izdelkov. Preiskave so pokazale, da ima izbrana mešanica HSSCC z oznako 9 v povprečju tlačno trdnost 82,25 MPa, cepilno trdnost 8,10 MPa, upogibno trdnost 27,10 MPa in vezivno trdnost 11,89 MPa.

Ključne besede: visoko trdni samozgoščevalni beton, mehanske lastnosti, kremenov pesek, prah marmorne pulpe

1 INTRODUCTION

Standard concrete is made of sand (fine aggregation) and gravel or stone of selected sizes and shapes. The interest in finding alternative aggregate materials is expanding. As aggregates generally account for 70–80 % of the concrete, they are broadly known as inactive fillers with little effect on the final concrete properties. Research has indicated that the absolute permeability, durability, dimensional consistency and resilience of concrete are of significant importance. Because of the rapid infrastructural development, the demand for common sand in developing countries is high. The residue and marble sludge present in various regions influence the soil fertility. The current exploration is done to prevent contamination and conserve the waste material.

The selection of building materials must also take into account environmental issues that are causing great concerns. Concrete is a naturally protected material with a base ecological cost per ton. In certain parts of the planet, extreme weather events occur more frequently. J. Fenger[1] and L. Saleh et al.,[2] reveal that the levels of emissions of greenhouse gases, principally carbon dioxide, increased from 280 µL/L to 370 µL/L parts, primar-

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ily during modern times. Generally, ordinary concrete includes around 12 % of mortar, 8 % of blending water and 80 % of the mass mixture. This implies that the concrete production consumes 9 billion tons of sand and rock and 1 billion tons of blending water every year, in addition to 1.5 billion tons of cement. Subsequently, the concrete production of 11.5 billion tons a year is the largest market in the world with respect to the use of capital.[1,2]

It is expected that by 2050 the concrete production will increase to about 18 billion tons (16 billion tons) per year. Because of the unabating issues relating to the environmental changes and sustainability in the building industry, the utilization of different wastes in the concrete production is getting progressively far-reaching. The concrete created by adding such wastes is now usually appreciated and can be a rival to the traditional concrete. There is also currently an analysis of the improvement of a special concrete such as self-compacting concrete although the state of the art is less evolved here.[3] Wang et al.[4] defined the modern advancement of concrete manufacturing, Okamura et al.,[5] first created self-compacting concrete (SCC) in 1986. In two fundamental manners, Bonen et al.,[6] showed the utilization of SCC, having certain advantages over the conventional concrete: (1) modern properties and (2) reinforced properties. Although SCC exhibits numerous special and general advantages, a higher demand for SCC in comparison with typical cement has restricted its applications.

In a study, an effort was made to lessen the expense of the development of SCC based on a new idea.[7] This type of self-compacting concrete resulted in a significant progress regarding the environment, wellbeing and protection, eradicating a few errors found by supervisors, decreasing the workload as well as reducing the time and costs of projects.[8] Replacing the conventional vibration technique and using the enhanced filling capacity, the new approach within a complex architectural design could reduce the workload and development costs. Second, the mechanical property of SCC is normally better than that of conventional concrete due to the perfect workability and width progression of fine sands, ascribed to the upgraded interfacial transition zone (ITZ) between the concrete adhesive and aggregates.[9,10] Contrary to the standard concrete, this additionally prompts reduced permeability and improved elongated and durability. De Azevedo et al.[11] described SCC as an extremely fluid concrete without vibrations during the positioning process. Thus, the fiscal, technological and environmental aspects of this form of concrete are particularly important. The highly cohesive design of the concrete allows it, without sacrificing homogeneity, to move around closely spaced reinforcement bars and restricted sections. A successful SCC production will lead to a new era of concrete manufacturing. The utilization of SCC will improve the general effectiveness of concrete structures. A few examinations of the new advantages, preparation of the mix, positioning methodologies and the power of various SCC blends were carried out.[12,13]

Nevertheless, the lifespan of SCC has been regularly tested with very little effort as opposed to the standard vibrated concrete. Due to a rapid population growth and increased demand for accommodation and new constructions, there are ongoing advances in civil engineering, for example, superior structures, long-range spans and higher compressive-strength of concrete, which is essential.[14] High-strength self-compacting concrete containing marble-sludge powder (MSP) and quartz sand (QS) as the fractional replacement of the fine aggregate (M sand) is used in this study to address these issues. River sand has now become a valuable material, allowing us to think about other options. Crushed rock is called sand (M-sand), having a fitting grain size. A coarse stone unit is broken and put into a special rock crusher, which accomplishes the fitting of the grain-size distribution, while the trampled material is washed away, removing the fine parts.

The qualities of M-sand and natural river sand are presented below. In M-sand, no flaky or coarse particles are present. M-sand is well rated and falls within the Zone II sand grading limits according to the IS 383 guidelines for grading limits. For crushed-stone sands, the code requires 20 % of fine grains of less than 150 μm. The specific gravity used for M-sand and river sand is 2.63 and 2.67, respectively. M-sand has a bulk density of 1593.7 kg/m^3 and for river sand, it is 1478.5 kg/m^3. The M-sand bulk density is slightly larger than that of river sand. The pH is 10.11 and 8.66 for M-sand and river sand, respectively. M-sand contains typical rock-forming minerals, for example, quartz, feldspar, micas, etc. Rock-forming mineral deposits, for example, quartz or feldspar, are essentially dormant.

The mica group does not interfere with the hydration of cement and the creation of strengths in mortars. The impact of the expansion of the MSP with the Portland concrete alters the substance in hydrates just as the microstructure.[15] The extraordinary advantages of the current concrete, like great usefulness, higher strength and better toughness, can be accomplished by consolidating a few chemical and mineral admixtures.[16] Strength is one of the main advantages of concrete because the underlying segments should have the option to support their weight and loads. For this reason, compressive-stress and splitting-tensile-strength experiments were carried out to determine physical, chemical and mechanical properties. To find the impacts of M-sand and MSP on the consistency and productivity of concrete, water stamping, electrical resistivity, ultrasonic pulse rate and semi-cell potential were tested. The results of this project ought to incorporate data regarding the reduction of SCC expenses as well as creation and use of SCC in the building industry.

The strength of architecture is one of the most significant contributions of concrete, whereby structural elements are able to support their weight and loads. The novelty of the research is:

Table 1: Chemical properties of cement, M-sand, marble-sludge powder and quartz sand (test metod IS: 4032-1968)

Sample	Fe_2O_3 *w*/%	MnO *w*/%	Na_2O *w*/%	MgO *w*/%	K_2O *w*/%	Al_2O_3 *w*/%	CaO *w*/%	SiO_2 *w*/%
M-sand	5.58	4.01	4.01	–	4.01	15.43	3.25	67.62
Marble-sludge powder	1.09	–	0.63	18.94	0.91	1.09	32.23	4.99
Quartz sand	0.07	–	13.64	0.32	0.35	1.44	11.57	72.4
Portland cement	4.10	0.96	0.86	0.96	1.18	5.98	60.78	20.99

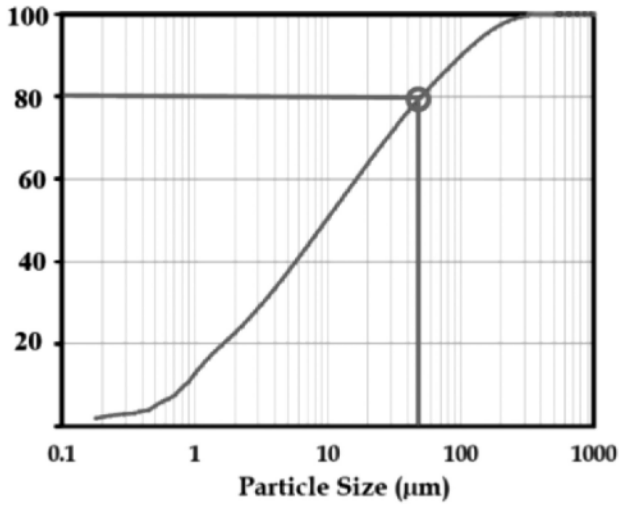

Figure 1: Particle-size analysis of MSP

- This project's findings provide information that can allow the reduction in the SCC costs and help to produce and use SCC in building industries.
- Nowadays self-compacting concretes are used widely in the construction field. Special structures, such as bridges, dams, etc., require high strength. Previously, only limited work was done on high-strength self-compacting concrete.
- In this study, quartz sand and marble-sludge powder were used for enhancing the high strength of self-compacting concrete and the resulting mechanical properties were studied.

2 MATERIALS

2.1 Concrete

Ordinary Portland cement (OPC) of grade 53 was utilized in the study in accordance with IS: 269:2015.[17]

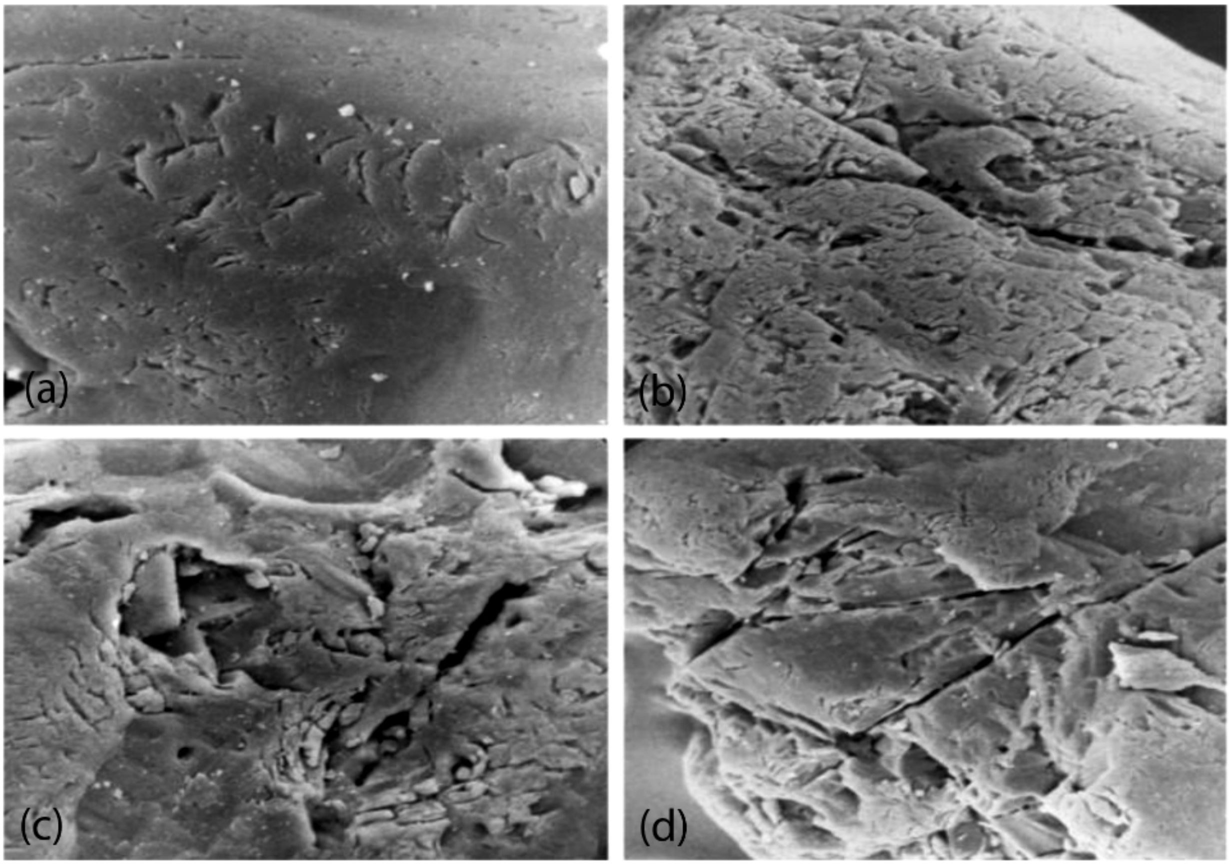

Figure 2: SEM images of quartz sand: a) smooth grain surface, b) smooth grain surface (1000:1), c) joined grain surface, d) deeply joined and corrugated grain surface

M-sand was brought from the nearby grinder facility; its specific gravity was in a range of 2.59 and it was added to concrete in line with IS 383-1970.[18] Coarse aggregates of up to 20 mm were held in a 12-mm IS sieve. Consumable water was utilized for the whole investigation. Physical and chemical properties of the cement, M-Sand, marble-sludge powder, and quartz sand are presented in **Table 1** and **Table 2**.

2.2 Marble-sludge powder (MSP)

MSP was obtained, while still wet, directly from the deposits of a marble plant. Before the test, wet MSP had to be cleaned. MSP incorporated various sorts of marble and numerous parts of marble. Using a 1-mm sieve, waste marble sludge was sieved.

2.3 Quartz sand

N. Kouras et al.[19] and M. Li et al.[20] utilized quartz sand as the base molding material. On account of the atmospheric impacts on the rocks and deposition of sediments, it had varying characteristics. Certain minerals fit storage conditions, for example, pellets or a quartz sand mine. Wet mining could also be carried out. The molding of quartz sand at mines includes washing and purifying, accompanied, if possible, by hydraulic classification, floatation and drying in a revolving and fluidized aggregate bed.

Table 2: Physical properties of cement, M-sand, marble-sludge powder, quartz sand and coarse aggregate

Physical tests	Cement	M-sand	MSP	Quartz sand	Coarse aggregate
Specific gravity	3.15	2.75	2.4	2.5	2.73
Water absorption (%)	–	3	–	3.2	1
Density (kg/m^3)	1506	1777.3	–	1442.3	1551

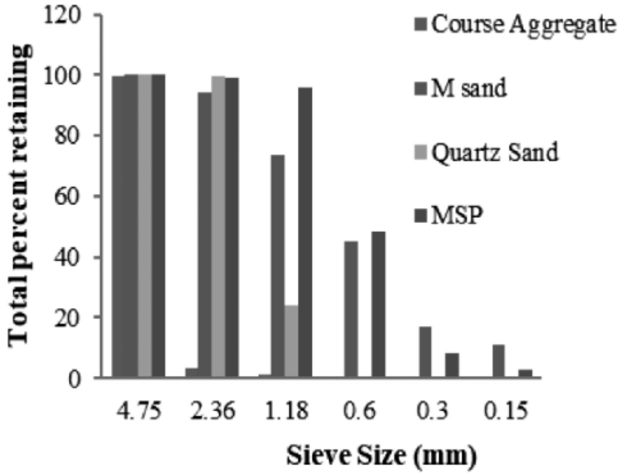

Figure 3: Collective grading of CA and FA (M-sand, MSP, quartz sand)

2.4 Admixture for a high-range water decrease

For the production of high-workability concrete, economically accessible high-range water-reducing admixture (HRWRA) Master Glenium SKY 8233 from Anco India Chemicals Private Limited – a water treatment chemical manufacturer in Chennai, was utilized. The specific gravity of the component was 1.08 and the solid material was no less than 32 *w*/%. Master Glenium SKY 8233 is a modern, modified polycarboxylic ether-based admixture. The product was designed specifically for high-performance concrete applications where the highest reliability and performance are required.

Table 3: Selected mix proportions for the HSSCC tests

MIX ID	Cement (kg)	M- sand (kg)	MSP (kg)	Quartz sand (kg)	CA (kg)	Water (L)	Super plasticizer (L)	W/C ratio	Grade of concrete
HSSCC1	550	840.15	0	0	723.58	236.5	1.375	0.43	M70
HSSCC2	550	672.12	0	168.03	723.58	236.5	1.375	0.43	
HSSCC3	550	672.12	63.011	105.01	723.58	236.5	1.375	0.43	
HSSCC4	550	672.12	126.02	42.00	723.58	236.5	1.375	0.43	
HSSCC5	550	504.09	0	336.06	723.58	236.5	1.375	0.43	
HSSCC6	550	504.09	63.011	273.04	723.58	236.5	1.375	0.43	
HSSCC7	550	504.09	126.02	210.03	723.58	236.5	1.375	0.43	
HSSCC8	550	336.06	0	504.09	723.58	236.5	1.375	0.43	
HSSCC9	550	336.06	63.011	441.07	723.58	236.5	1.375	0.43	
HSSCC10	550	336.06	126.02	378.06	723.58	236.5	1.375	0.43	
HSSCC11	550	168.03	0	672.12	723.58	236.5	1.375	0.43	
HSSCC12	550	168.03	63.011	609.10	723.58	236.5	1.375	0.43	
HSSCC13	550	168.03	126.02	546.09	723.58	236.5	1.375	0.43	
HSSCC14	550	0	0	840.15	723.58	236.5	1.375	0.43	
HSSCC15	550	0	63.011	777.13	723.58	236.5	1.375	0.43	
HSSCC16	550	0	126.02	714.12	723.58	236.5	1.375	0.43	

3 EXPLORATORY PROGRAM ON THE HARDENED CONCRETE

3.1 Mix proportions

The exhaustive mix proportions are presented in **Table 3**. The mix design was organized for the M70 grade of HSSCC. Three different percentages of MSP (5 %, 10 %, 15 %) and various percentages of QS, as the substitute for M-sand, were used. Diverse workability tests, for example, slump-flow, T500 time, V-funnel time, J-ring step height and L-box passing-ratio tests, using the fresh state of the concrete mixes, were performed for all the SCC combinations according to the rules given in the EFNARC standard.[20,21] The water-to-binder ratio for all combinations was set at 0.43. The binder content of all mixtures was 550 kg/m^3.

3.2 Mixing design and specimen preparation

A total of 288 test mixes were taken into account, considering different mixing conditions, such as the volume of MSP, superplasticizer, water/powder ratio or fine aggregate/coarse aggregate ratio (FA/CA), to select an acceptable mix utilizing local marginal aggregates. A sum of 275 test mixes was made by changing the SP ratio, fine-to-coarse aggregate ratio, MSP substance and water powder. The concrete was mixed with a laboratory blender and layered into molds. Concrete compaction was accomplished utilizing a vibrating table. After 24 h, the specimens were cured by being submerged together with the molds. Permeability checks were done after 28 days of curing.

3.3 New properties of the concrete

The slump-flow, J-ring, U-box, L-box and V-funnel tests were conducted for both mixtures. The slump-flow range was 650–800 mm as indicated by the EFNARC guidelines.[21] The J-ring test used a J-ring made in Japan and followed the slump-flow test. The L-box tested the filling and passing ability of SCC and the U-box test was also utilized for computing the SCC filling ability. The V-funnel tested the fluidity and segregation easiness of the concrete.

Table 4: New properties of HSSCC and acknowledged values

Experiment type	Observed values	Acceptable range
Slump-flow diameter (mm)	700	600–800
Slump-flow T500 (s)	3	2–7
J-ring flow diameter (mm)	750	580–780
J-ring height $H_{in} - H_{out}$ (mm)	7	0–15
L-box ratio	0.84	0.75–1.0
V-funnel T0 (s)	8	6–12
V-funnel T5 (s)	3	T0–(T0 + 3)

3.4 Mechanical properties of the concrete

Mechanical properties were tested, for example, compressive strength and splitting tensile strength. For HSC and HSSCC, the compressive strength and splitting tensile strength were studied. After (7, 28, 90) d, the compressive strength and bond strength were tested on a cube specimen of (150 × 150 × 150) mm. To test the impacts of MSP and M-sand on the tensile properties of the concrete, the indirect strategy of applying stress during the process of splitting was used. Compared with different methodologies, divided tensile strength is a more effective methodology for estimating the concrete tensile strength (a minor coefficient of dissimilarity). To determine the impact of M-sand with MSP on the tensile properties of the concrete, the splitting tensile strength of elevated concrete cylindrical specimens of 150 mm in diameter and 300 mm in length was tested and the flexural strength of prism specimens of (100 × 100 × 500) mm was checked.

4 RESULTS AND DISCUSSION

We produced 288 preliminary concrete mixes and their examinations were conducted in terms of strength, passing ability, filling ability and workability.[6] Their performance was analyzed and a comparison was made as shown below.

4.1 Compressive strength

Figure 4 presents the compressive-strength test results. In this trial, the results for the M70 grade concrete were assessed after (7, 28, 90) d. After seven days, the M70 grade concrete showed higher compressive strength than the normal concrete with crushed-rock dust. Concrete of all grades achieved higher compressive strength after 28 d and 90 d, because of the marble-sludge powder (MSP) and quartz sand (QS). So, the concrete strength was improved because the MSP reduced the cement pores. Moreover, MSP, acting as a filler, changed the concrete properties to a great extent, as determined already by B. Łaźniewska-Piekarczyk et al.[23] The specific reactivity of MSP fillers includes the transition-zone re-

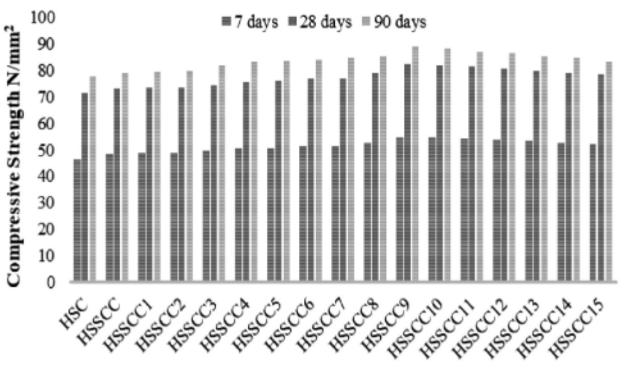

Figure 4: Performance analysis concerning compressive strength

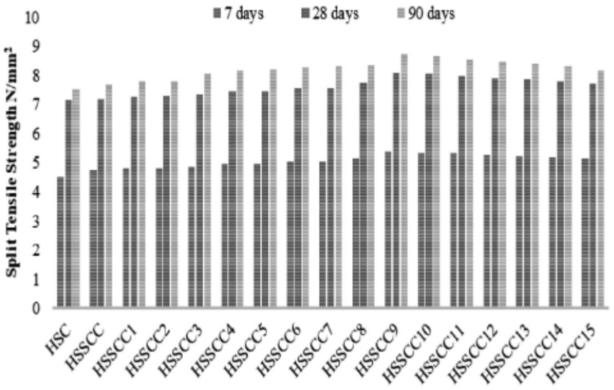

Figure 5: Performance analysis concerning tensile strength

action between the cement paste and filler, a change in the CSH, an accelerating impact on the hydration of C3S and the use of calcite. The test shows satisfactory compressive strength.

4.2 Splitting tensile strength

The performance analysis regarding the tensile strength is shown in **Figure 5**. In this test, the elasticity of the M70 grade concrete was assessed after (7, 28, 90) d. There is an improvement in the elasticity when comparing self-compacting concrete with normal concrete with crushed-rock dust and normal concrete with river sand. A large amount of M-sand causing higher tensile

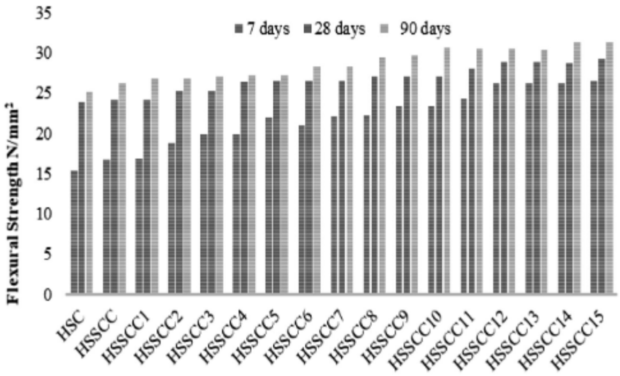

Figure 6: Performance analysis concerning flexural strength

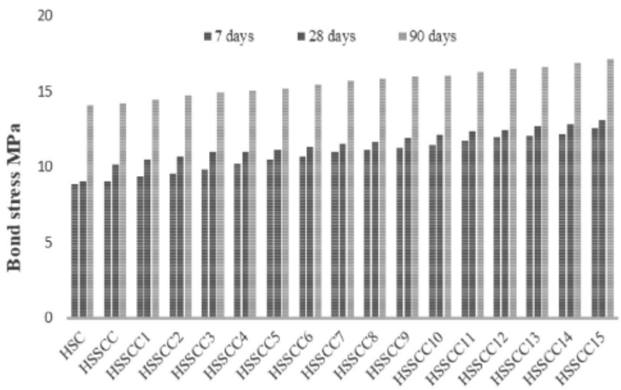

Figure 7: Performance analysis concerning bond strength

strength was used to upgrade workability, reduce w/c and increase density. The calcium silicate hydrate exhibited by MSP responds to free $Ca(OH)_2$. By densifying the concrete matrix, both durability and strength are upgraded, while the quantity of the binder is expanded. When compared with the river sand, the crushed-rock particles have immensely rough surfaces and the bond strength is improved with the assistance of the rough surfaces. A change in the compressive strength does not at all influence the relative amount of splitting tensile strength against the compressive strength.

4.3 Flexural strength

For 0-% HSSCC, 5-% HSSCC, 10-% HSSCC and 16-% HSSCC, flexural strengths of (4.67, 5.75, 5.67, 4.88) MPa are acquired. The flexural strength increases slightly each day. **Figure 6** gives a graphical presentation of flexural strengths.

4.4 Pull-out-strength test

Figure 7 presents the bond-strength test results. In this test, the M70 grade concrete was analyzed after (7, 28, 90) d. The bond strength increases due to marble-sludge powder (MSP) and quartz sand (QS) after (7, 28, 90) d. We used a concrete cube of 150 mm with a rebar of up to 20 mm from the top of the cube. The rebar was coupled more than the top surface for a discriminating length to facilitate the holding of the rebar on the component. The pull-out test was done with a 40T universal testing machine with a dial gauge meter with a least count of 0.01 mm. One of the features is receiving the systematic tip of the rebar of 10 mm and the other at 250 mm below the concrete face on the contrasting face. The enlarging of the bar was done to analyze the slip. The discrepancy in the readings of one dial gauge was taken as an eligible slip of the rebar with the concrete surface. The ideal bond strength was achieved at the end of the investigation.

4.5 Bond stress

For every pile level, the normal bond stress τ is defined as the average stress of the reinforcing bar close to the concrete and along the entrenched part of the bar as follows:

$$\tau = F/\eta dl \tag{1}$$

where F – the pull-out control of the steel bar
l – rooted bond length
d – diameter of the steel bar.

5 CONCLUSIONS

The entire experiment shows that the physical and mechanical properties improved with the integration of the fine aggregate. These findings are of great significance since huge amounts of fine particles are needed for this sort of progressive concrete. Because of its high fineness, the marble-sludge powder is very effective at keeping the concrete cohesiveness. It is concluded that the powder of quartz sand and marble sludge can be utilized as an alternative, acting as a fine aggregate. From the current assessment, the following conclusions can also be drawn:

- The powder obtained from blocks of marble can be utilized as the filler added to the cement used for self-compacting concrete. Chemical compositions of quartz sand and marble sludge are equivalent to that of cement.
- The replacement of fine aggregate with 15 % of marble-sludge powder and 45 % of quartz sand (HSSCC concrete) led to an extraordinary result with regard to the strength and consistency. The findings show that the HSSCC 9 mix exhibited better compressive strength, splitting tensile strength, flexural strength and bond strength, having values of 82.25 MPa, 8.10 MPa, 27.10 MPa and 11.89 MPa, respectively. The amount of cement-MSP pastes affected the rheological qualities of fresh SCC, its compressive power and bond strength. The four types of HSSCC with different amounts of cement-MSP paste had a strong correlation with the properties of fresh and hardened concrete. Fresh HSSCC exhibits improved behavior and it is ideal for use in the mixes containing white cement for architectural concrete.
- The combined utilization of quartz sand and MSP was excellent because of their effective micro-filling and pozzolanic activities. The findings of this study, therefore, provide clear recommendations regarding the use of quartz sand and MSP in the concrete production.
- Compared to HSC and control HSSCC, the HSSCC with the sand being replaced by 15 % of MSP and 45 % of quartz sand exhibits improvement in the compressive strength, tensile strength, flexural strength and bond strength.

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