Performance of Sustainable Self-Compacting Fiber Reinforced Concrete with Substitution of Marble Waste (MW) and Coconut fibers (CFs)

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Research Article

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Performance of Sustainable Self-Compacting Fiber Reinforced Concrete with Substitution of Marble Waste (MW) and Coconut fibers (CFs)

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Abstract: - Self compacting concrete (SSC) is also brittle nature, resulting in abrupt failure without giving any warning, which is unacceptable for any construction materials. Therefore, SCC requires tensile reinforcement to increase tensile capacity and avoid the undesirable brittle failure of SCC. However, fiber improved tensile capacity more efficiently than compressive strength. Therefore, it important add pozzolanic material to fiber reinforced concrete to obtain high strength, durable and ductile concrete. This research is carried out to evaluate the qualities of concrete with addition of waste marble and coconut fiber in concrete. Marble waste used as binding (pozzolanic) materials in proportion of 5.0 to 30% by weight of cement in increment of 5.0% and concrete is reinforced with coconut fiber in proportion of 0.5% to 3.0% by weight of cement in increment of 0.5 %. Rheological properties were assessed through its passing ability and flowability by using Slump flow, Slump T50, L-Box, and V-funnel tests while mechanical performance were evaluated through compressive, split tensile, flexure and pull out tests. Tests results indicate that marble waste and coconut fiber decrease the passing ability and filling ability of SCC. Furthermore, tests results indicate that marble waste up to 20% and coconut fiber addition 2.0% by weight of cement have a tendency to enhance the mechanical strength of SCC. Finally, Statistical analysis (RSM) was used to optimize the combined substitution of marble waste and coconut fiber to obtain high strength concrete.

Keywords: - Rheological properties, Statistical analysis (RSM), Coconut fiber, Filing and passing ability, compressive Strength.

1 Introduction

Self compacting concrete is particular types of concrete which is flowable , non segregated and by its own mass spread into place and fill the formwork even in the presence of congested reinforcement. [1]. In 1986, the concept about SSC was proposed [2]. But 1988 Japan was first country which was successfully able to develop the prototype of self compacting concrete (SCC).

The concept of environmental development believes that environmental reserves must be considered as restricted goods and the wastes must be reasonably controlled. Growing quantities of accumulated garbage, up to 2500 million tons per year over the world [3] which promote the scholar to a built modern technique of dumping. In the cement production industry, there are several opportunities to utilized waste raw material in concrete [4]. Waste can be utilized as fine or coarse aggregate or cement in concrete.

For a good quality concrete mix, fine aggregates must be clean, hard, strong, and free of immersed chemicals and more fine materials that may possibly produce the weakening of concrete. Unluckily, the

majority of the natural sand utilized is either rolled sand, sand of river, dune sand, and sea sand is chosen for the economy and the accessibility [5]. Properties of sand disturb the strength performance of concrete, as sand is an important ingredient of concrete.

Various productions are the cause of waste which are created as a byproduct during the production procedure. It is recommended that Marble be able to be utilized in the building production to make Cement Concrete [6]. The aim of this article is to utilize waste marble as a partial substitution of sand which takes from the marble factory. Real estimate about the amount of waste generated in Pakistan from the marble industry are unavailable since it is not analyzed or supervised by the government or any other political party. More references assess that 20 to 25% of the marble delivered in the form of slurry through the cut off procedure [7]. These marble wastes are present in the environment and cause to pollution.

Subsequently ancient occasions marble has been commonly utilized as a cementitious material in cement concrete. The factories disposing of the marble residue material, which contain of a extremely fine ash, currently comprises one of the ecological problem throughout the world [8]. Management of the marble powder in various factories regions particularly the paper, agriculture, glass, and building factories would assist to care for the environment [9]. Through the quarrying procedure and in the cleaning of marble dust, marble powder is seen as a rubbish material [10].

Numerous established nations have set in action permissible rules about the recovery of factories waste trying to decrease the quantity of rubbish and to guarantee rubbish reprocessing [11]. Let consider the sample of Japan in visible of us, a nation that effectively improved the reprocessing rate of concrete waste up to 98% utilizing waste material as aggregate [12]. It has been identified that the Marble powder delivered through treating corresponds to almost 40 percent of the finishing product from the marble factory [13]. They also described that workability of concrete reduce with the supplement of marble powder. Katuwal et al also suggest that marble as a fine aggregate reduce workability of concrete [14]. They detected that compressive strength is enhanced up to 50 percent substitute of fine aggregate with marble dust which is almost 12 percent greater than from reference concrete [15]. Compressive strength and flexural strength of concrete are improved almost 28 percent and 13 percent correspondingly at 50 percent substitution and then steadily decline with the supplement of marble dust [16]. Opposition to the acid of concrete including marble dust was slightly less in comparison to reference concrete [17]. It has been Indicated that Marble dust can be easily utilized in the cement concrete production [6]. Although marble increase mechanical performance of concrete considerably, but still concrete has less tensile strength which result brittle failure. Therefore, concrete still some of tensile reinforcement to improve tensile capacity. Fibers is one of the most prevalent method to enhance tensile capacity of concrete.

Through extensive research, it has been determined that the performance of concrete were significantly increased because of the addition of fibers to concrete [18–21]. Improving the production technique of SCC is increasing day by day in concrete production [22]. ACI 544.5R-10 stated that thick fibers are lower efficient in reducing the plastic shrinkage cracks width as compare to thin fibers [23]. Most thin diameter

microfibers are particularly effective in reducing plastic shrinkage cracking of concrete because larger surface area of fibers [24]. Moreover, the use of fibers helps in reducing the porosity and bleeding of concrete [25–28].

Various kinds of fibers are utilized to reinforce concrete such organic and inorganic fibers [29]. The choice of the kind of fibers is depends on different aspects such area, length, tensile strength modulus of elasticity and the material from which it is made. Furthermore the amount to which these fibers effect the performance of concrete [30]. Mostly fibers are classified into two types, one is metallic and the other one is nonmetallic. Metallic fibers are mainly steel fibers whereas nonmetallic are glass fiber, propylene fiber, carbon fibers [31].

Research Significance

In existing literature shows that the fibers increased mechanical performance of concrete particular tensile strength more effectively than compressive strength. Ahmad et [32] used steel fiber in concrete and reported steel fiber increased tensile strength more effectively than compressive strength. Further research was recommended [32] that pozzolanic materials must be added to fiber reinforced concrete to achieved high strength , durable and ductile concrete. Also reported that steel fibers are too costly as well as easily corroded. Therefore, the primary objective of this research is to utilize marble waste in SCC. Secondary objective of this research is utilizing coconut fibers instead of steel fibers which are costly as well as easily corroded. Third objective of this is research was to optimized substitution ratio of marble waste and coconut fibers with help of statistical analysis (RSM) to achieved high strength self-compacting concrete. Finally experimental results and predicted results from statistical analysis (RSM) will be compared.

2.1 Materials

2.1.1 Cement

Normal setting time cement as per according to ASTM C150 [33], were used as binding material throughout in this study. Furthermore, different its aspects were given Table 1.

Table 1 Properties of Cement

Chemical Property	Outcomes (%)	Physical Property	Outcomes
CaO	64.7	Size	$\leq 75\mu$
SiO ₂	22.9	Fineness	92%
Al ₂ O ₃	4.4	Normal Consistency	31%
Fe ₂ O ₃	3.0	Initial Stetting Time	33min
MgO	1.5	Final Stetting Time	410min
SO ₃	1.9	Specific surface	322 m ² /kg
K ₂ O	1.4	Soundness	1.70%
Na ₂ O	0.2	compressive Strength	42Mpa at 28 days

2.1.2 Coconut Fibers (CFs)

Coconut fibers having 80 to 100 mm long length with a diameter of 0.5 to 1.0mm were utilize in this study. Its properties are given in Table 2.

Table 2 Properties of CFs

Physical Property	Results
Length	80 to 100 mm
Diameter	0.5 to 1.0 mm
Breaking Elongation	25 %
Density	1.4 g/cc
Young's Modulus	4.5GPa

2.1.3 Aggregate

Nearby accessible rive sand in saturated surface dry (SSD) condition were utilized as a fine aggregate throughout in this study. Normal weight crush aggregate in saturated surface dry (SSD) condition were utilized as coarse aggregate in this study. Both (fine and coarse aggregate) were collected from Margallah Taxila Pakistan. Furthermore, different parameter which influence the performance were evaluated in laboratory and presented in the following Table 3.

Table 3 Properties of Aggregate

Physical Property	Fine aggregate	Coarse Aggregate
Particle Size	4.75mm to 0.075mm	19.5mm to 4.75
Fineness Modulus	2.52	4.23
Absorption Capacity	4.08%	2.9%
Moisture Content	1.8%	1.2%
Bulk density (kg/m ³)	1566	1575

2.1.4 Marble Waste (Mw)

Marble waste (Mw) were procured from the National marble factory industrial zone Risalpur Pakistan. collected were grinded at Pakistan council of scientific and research lab Peshawar Khyber Pakhtunkhwa, Pakistan. Table 4 depicts different properties (chemical and physical) of marbles waste used in this research study.

Table 4 Properties of Marble Waste (MW)

Chemical Property	Percentage (%)	Physical Property	Results
CaO	47.55	Color	White
SiO ₂	7.13	Specific Gravity	2.60
Al ₂ O ₃	22.20	Clay (%)	0.6
Fe ₂ O ₃	8.23	Density (kg/m ³)	1480
MgO	6.32	Absorption Capacity	2.30
SO ₃	3.07	Moisture Content	0.60
K ₂ O	2.9	Fineness Modulus	2.52
Na ₂ O	2.6		

2.1.5 High Range Water Reducing Admixture (Superplasticizer)

Chemrite-530 has been utilized as a super plasticizer since it is a high-range water-reducing mixture that is also considered non-toxic and non-hazardous in compliance with appropriate health and safety regulations. The superplasticizer satisfies the requirements of EN 934-2 T 3.1/3 [34] and ASTM C-494 Type F [35] as well as other known practices. Table 5 lists some of the superplasticizer's typical features.

Table 5 Properties High Range Water Reducing Admixture

Property	Result
Color	Dark Brown
Relative density	1.58 at 27°C
Chloride content	< 0.2%
Physical state	Liquid

2.2 Experimental Setup

To attain the project's objective, an experimental study program was created, and it was segregated into two phases. In the first phase, trial mixes were created to meet the technical requirements for SCC[1] Six mixes were created by various proportions of marble waste (MW) and coconut fibers (CFs) in the second stage to find out the the impact of marble waste (MW) and coconut fibers (CFs) on self-compacting concrete (SCC), which were developed on the basis of the first stage. Table 6 illustrates typical acceptability requirements for self-compacting concrete as defined by the specific requirements for self-compacting concrete with maximum particle size up to 20mm.

Table 6 Acceptance Criteria for SCC

Experiment	Units	Lower Limit	Upper Limit
Slump Flow	cm	60	80
Slump T50	Seconds	2.0	5.0
L-Box	H2/H1	0.8	1.0
V-Funnel	Seconds	6.0	12

2.2 Size of Specimen

Slump flow, Slump T50, L-Box, and V-funnel tests were used to assess rheological characteristics [36]. moreover, as per ASTM C39/C39M [37], standard-sized cylinders (150 mm in diameter and 300 mm in length) have been used to test the compressive strength at seven, fourteen, and twenty-eight-day intervals. The tensile strength of similar cylinders of standard size (150x300mm) has also determined by casting and testing them in the laboratory. A beam with dimensions of (150x150x500mm) would be casted and tested to determine its flexure strength in accordance with ASTM [38]. Considering ASTM [39], a cube of standard dimensions (150mm³) has been used to determine bond strength. For each test, three specimens have been tested at seven, fourteen, and twenty-eight days, and the mean value of the specimens have opted as the strength. The specimens have prepared according to the ASTM C-31 [40] technique, and the compaction was done manually by Roding in three layers with 25 blows each layer, as described in the standard. Eight different mixtures were created to investigate the impact of marble wastage and coconut fibers on the performance of solidified and fresh concrete. Table 7 presents the details of the mixes.

Table 7 Trials Batches of SCC

Materials	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8
Cement (kg/m ³)	425	425	425	425	425	425	425	425
Sand (kg/m ³)	625	625	625	625	625	625	625	625
Crush (kg/m ³)	1270	1270	1270	1270	1270	1270	1270	1270
W/C	0.50	0.50	0.50	0.50	0.60	0.60	0.60	0.60
Superplasticizer (kg)	-	2.12	4.25	6.37	-	2.12	4.25	6.37

3 Results

3.1 First Stage

In the first phase, eight different mixes have created to obtain the best feasible blend that would meet the requirements of Technical Specification for the product (SCC). As a result of the research, Table 8 exhibits the fresh characteristics of SCC for each trial mix tested using various testing techniques (Slump Flow, Slump T50 Spreads, L-Box, and V-Funnel). Table 8 provides the true picture that Mix 6 will gratify the variety of different tests (Slump flow, Slump T50 Spread time, L-Box, and V-funnel) stated by the specific requirements for self-compacting concrete. Others believe that the mixture does not gratify the range of such testing. Hence, in order to get the good self-compacting concrete mix, Mix 6 is regarded the best mix. It may be used as a reference concrete (control) with varying proportions of MW and CFs for further experimental works.

Table 8 First Stage Results

Tests Methods	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8
Slump (mm)	535	542	568	622	572	775	710	768
L-Box Test (H2/H1)	0.60	0.68	0.72	0.83	0.76	0.94	0.96	0.98
V-Funnel Tests (Sec)	19	16	15	11	14	11	5	3
T50-Slump Flow	11	8	7	5.2	6	4.5	2.8	2.2
Remarks As per EFNARC	Too Stiff f+ Segregation	Too Stiff	Small Stiff	Small Bleeding	Small Stiff	Good SCC	Small Bleeding	Too Bleeding + Segregation

3.2 Second Stage

Mix 6 (SCC) was chosen for beyond investigational work according to the results obtain in first stage. Hence, the next stage of the investigational work was performed on Mix 6 (SCC) with differing proportions of Mw and CFs. Five blends were planned at the next phase after attained the requirement of technical guideline for self-compacting concrete (Mix 6). Different proportions of Mw and CFs were incorporated to fresh SCC. The proportions of Mw were from 5.0% to 30% by weight of cement increment in 5.0% and CFs were incorporated from 0.5% to 3.0% by weight of cement in increment of 0.5%. Table 9 indicates concrete blend percentages of self-compacting concrete with differing proportions of Mw and CFs.

Table 9 Quantification of materials

Mix ID	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Superplasticizer (kg)	Marble Waste (kg)	Coconut Fibers(kg)
Control	425	625	1275	2.12	-	-
Mw-5%	403	625	1275	2.12	21	-
Mw-10%	382	625	1275	2.12	42	-
Mw-15%	362	625	1275	2.12	63	-
Mw-20%	340	625	1275	2.12	85	-
Mw-25%	319	625	1275	2.12	106	-
Mw-30%	298	625	1275	2.12	127	-
CFs-0.5%	425	625	1275	2.12	-	2.12
CFs-1.0%	425	625	1275	2.12	-	4.25
CFs-1.5%	425	625	1275	2.12	-	6.37
CFs-2.0%	425	625	1275	2.12	-	8.5
CFs-2.5%	425	625	1275	2.12	-	10.6
CFs-3.0%	425	625	1275	2.12	-	12.75

3 Results and Discussion (Second Stage)

3.2.1 Rheological Performance

3.2.1.1 Slump Cone and SlumpT50

Figure 1 and Figure 2 illustrate the results of the experiments done on slump flow and slump T50, with different proportion of marble wastes and coconut fibers. The highest value slump flow value was achieved by substituting marble waste at a rate of 0 percent (control), while the lowest slump flow value was achieved by substituting 30 percent of marble waste. As the percentage of marble waste increased from 0 to 30% by weight of cement, the time required to spread concrete into a 50 cm diameter (slump T50) increased. The time required to spread concrete into a 50 cm diameter (slump T50) reached its maximum level when the substitution rate of marble waste was 30% by weight of cement into SCC which causes a decrease in flowability. It can be attributed to the particle shape (flat or elongated) and surface texture (rough) of the marble waste, both of which escalates internal friction between the concrete materials. It has been also reported that, marble waste decreased workability of concrete due rough surface texture. Crushing of marble waste into the required size results rough surface of marble waste as compare cement [41]. However, all of the SCC mixtures are within the limits defined by the technical standard for SCC and have excellent flowability [1].

Figure 1 Slump Flow Results

As for CFs, the Slump flow value decreases as the proportion of CFs in the mixture increases. As indicated in Figure 2, the maximum slump value was achieved with 0 % substitution of coconut fibers (control concrete), while the lowest slump flow was achieved with 3.0 % replacement of CFs. The findings of tests show that as the proportion of coconut fibers in SCC increased, Slump flow reduced and Slump T50 value

increased, respectively because of decreased workability of SCC. The decrease in workability of concrete mixes when coconut fibers are added may be linked to the increased surface area of coconut fibers (CFs), which necessitated the use of more cement paste to coat them, resulting in less cement paste being available for lubrication. Coconut fibers also increased internal friction between the aggregate and the fibers, requiring additional cement paste to decrease internal friction. However, coconut fibers up to a 2.0 % inclusion resulted in Slump flow and Slump T50 values that were within the permissible range specified by the technical standard for SCC and had a good filling capability. But higher dosages of coconut fibers (2.5 % and 3.0 %) result in Slump flow and Slump T50 values that are outside of the range specified by the technical standard for SCC. Therefore, higher dose of superplasticizer is required for the mix of CFs (2.5 % and 3.0 %).

Figure 2 Slump T50 Results

3.2.1.2 L box and V funnel

The ability of self-consolidating concrete to pass the L-Box test was determined using this method. A similar trend to slump flow was observed in the passing ability of concrete, with the proportion of marble waste increasing from the level of 0 to 30 % with respect to weight of cement as illustrated in Figure 3. The passing ability of SCC decreases as the proportion of coconut fibers rises from the range of 0 to 3.0 % with respect to the weight of cement, which is parallel to the pattern of slump flow. According to the technical specifications for SSC, the usual permissible range of blocking ratio for excellent passage ability of SSC is in between 0.8 to 1.0. It can be observed from the findings that all of the marble waste mixes have a L box ratio between 0.8 and 1.0, which indicates that these mixes are within the limitations defined by the technical standard for self-compacting concrete and are thus fall acceptable range of SCC [1] having good passing ability. Figure 3 demonstrates that mixes containing 0 to up to 2.0 % coconut fibers have an L-Box ratio

(H₂/H₁) value ranging between 0.80 and 1. In other words, since the coconut fiber content of these mixtures (0 to up to 2.0 percent coconut fibers) fall within the limit define by the technical specifications for SCC and possess excellent filling and passing abilities. However, at higher dosage of CFs (2.5 % and 3.0 % coconut fibers), L-Box test ratio (H₂/H₁) is 0.72 and 0.65 respectively which fall out of the range as specified by technical requirements for SCC, as shown in Figure 3. Although [42] concluded that blocking ratio up to 0.60 possess good passing ability. However, technical specification for SCC states that the SCC has a good passing ability when the blocking ratio value (H₂/H₁) in the L box test is more than 0.8 [43].

Figure 3 L – Box Results

Flowability of self-compacting concrete (SSC) was checked through V-Funnel test. Flow time of V funnel test indicate the flowability of SCC. Increased flowability associates to shorter flow time. Self-compacting concrete flow decreases as percentages of marble waste and coconut fibers increased as illustrated in Figure 4 . Maximum flowability was found when the substitution of marble waste was set to zero percent, while lowest flowability was found when the substitution of marble waste was set to 30 percent. All marble mix waste streams exhibit flow time ranging from 6 seconds to 12 seconds, which satisfies the requirements of SSC [1] and have good flowability. As for coconut fibers, maximum flowability was found at 0% substitution of CFs, whereas lowest flowability was found at 3.0% substitution in coconut fiber. Flow time for mix (0 to up to 2.0 percent coconut fibers by weight of cement) is between 6 sec and 12 sec, which is within the permissible range specified by the technical standard for SCC (as shown in Figure 4.) In contrast, at greater dosages of coconut fibers (2.5% and 3.0% coconut fibers), the flow time is 14 seconds and 17 seconds, respectively, which is beyond the range specified by technical requirements for SCC. As a result, it is suggested that coconut fibers be used up to 2.0 % by weight of cement. It is also advisable to employ the use of coconut fibers up to 3.0 %, by weight of cement with the addition of a greater dose of superplasticizer.

Figure 4 V Funnel Results

3.2.2 Mechanical Performance

3.2.2.1 Compressive Strength

Compressive stress is the measure of the concrete's ability to resist the highest compressive load divide by cross sectional area of sample. A cylindrical specimens of standard size 150mm diameter and 300mm length were casted and tested for compressive strength under the standard procedure of ASTM C39/C39M [37].

Figure 5 illustrates the compressive strength of various marble waste dose levels. The compressive strength rises with the increase of marble waste up to 20%. It has been also reported that marble waste increased the compressive strength [43]. At a dose of 20% of the marble waste shows maximum compressive strength as compared to the blank or reference concrete. However, beyond 20% of marble waste compressive strength decreased gradually. The positive impact of marble waste on compressive strength is due to pozzolanic reaction in which SiO_2 (silica) in marble waste react with CH (calcium hydrate) of cement yields more C-S-H (calcium silicate hydrate) gel which is additional cementitious compounds [44]. At higher dose of marble waste beyond (20% by weight of cement), strength is reduced owing to dilution effect, resulting in alkali-silica reaction due to the presence of more unreactive silica. Also a higher dosage, compaction becomes more difficult due lack of workability, which results in increased porosity of concrete, leading to porous concrete which ultimate results lower compressive strength [45] . Based on

result, it is suggested that marble waste can be utilized as binding material up to a maximum of 20% by weight replacement.

Figure 5 Compressive Strength Results

As for coconut fiber concern, Compressive strength increased up to 2.0% addition of CFs and then decreased gradually as shown in Figure 5. It has been observed that the compressive strength enhanced up to 2.0 percent inclusion of fiber [46]. In comparison with blank or reference concrete, a 2.0 percent dose of Coconut fiber yielded maximum compressive strength at 28 days of curing. The compressive strength, however, decreased by further addition of CFs (beyond 2.0%). The confinement of the fiber reinforcement on the specimen results positive influence on compressive strength. Compression causes lateral expansion, which is restricted by the CFs, leading to more compressive strength. The fibers are able to withstand tension and shear because of their strength [32]. Compaction process become difficult at higher dose (beyond 2.0%), due lack of workability which results lower strength. It has been reported that 1.5% of the fibers increased compressive strength almost 15%, as compare to reference concrete [47]. Fibers at 1.0% by volume produce a significant increase in the initial as well as the later ages mechanical performance of concrete. The highest improvement in 28-days strength was seen to be 29.15% [48]. Therefore, there is an optimal limit for Coconut fiber. According to the results of the tests, the optimal dose of Coconut fiber for strength is 2.0% by weight of cement.

Figure 6 shows a relative analysis in which the 28-day compressive strength of the control mix is taken as the reference mix, and from which, various mixes containing increasing percentages of marble waste and coconut fiber are compared. At 20 percent and 2.0 percent replacement of Mw and CFs, compressive strength is around 20% and 18% lower than the control (28 days) at 7 days curing, compared with the

control strength (28 days). At 20 percent and 2.0 percent replacement of marble waste Coconut fiber, the compressive strength of concrete is still only 8.0 percent and 5.0 percent lower than that of reference concrete/control (28 days) at 14 days curing, respectively. After 28 days of curing, the compressive strength of concrete is 17 percent and 21 percent greater than that of reference concrete when Mw and CFs is substituted at 20 percent and 2.0 percent, correspondingly, as comparison of reference concrete (28 days control concrete strength).

Figure 6 Relative Analysis of Compressive Strength

Response surface technique is a statistical tool whose primary goal is to maximize a response or output that may be affected by a variety of factors or input variables, such as the number of input variables. When there are several responses, it is critical to determine the combined optimal dose of both compounds that does not maximize just one reaction [49]. In this study dependent variable are dose of Mw and CFs while independent variable is strength.

To investigate the combined effects of Mw and CFs on the compressive strength, a 3D response surface and contour plot were developed in the Minitab software for the Mw and CFs verse compressive strength at the age of 28 days curing. To assess best possible dose MW and CFs in SCC, 3D response surface was transformed into contour plot in which 18% Mw and 1.8% CFs were chosen from contour plot showing compressive strength 23 Mpa as given in Figure 7 and Figure 8. To justify the computed strength of contour plot for compressive strength of concrete at 28 days curing, the same dose of 18% Mw and 1.8% CFs were cast and tested experimentally in a concrete laboratory. It can be seen that the experimental value was very near to the anticipated value, indicating that the response surface models were correctly computed.

Figure 7 3D Response Surface for Compressive Strength

Figure 8 Contour Plot for Compressive Strength

3.2.2 Split Tensile Strength

Split tensile strength can be defined as the tensile stresses produced as a result of applying tensile force to the concrete sample in such a way that cylindrical sample split at vertical diameter. It is an indirect technique for examining the tensile strength of the concrete. split tests were executed on cylindrical samples

of 150 mm diameter and 300 mm height in accordance with ASTM C496-71 [50], at the ages of 7, 14 and 28 days of curing.

Figure 9 depicts the split tensile strength of concrete with various doses of the waste marble. As split tensile strength is a function of compressive strength, similar to the compressive strength, split tensile strengths were improved when the proportion of marble waste was increased up to a maximum of 20% replacement, after which they began to decline progressively. Maximum split tensile strength was achieved with a 20% substitution of marble waste, and minimum split tensile strength was achieved with a 0% replacement of marble waste as compared to the results (blank mix). In comparison to natural aggregate, the marble wastage has a greater carbonate content. This increases the connection between the aggregate and the cement paste, which is the cause for the rise in compressive strength of concrete at various curing ages [17]. The pozzolanic reaction of marble waste, which results in the formation of extra cementitious compounds, is responsible for the beneficial impact on split tensile strength [51]. According to certain reports, marble waste exhibits pozzolanic characteristics if the particle size that is smaller than that of cement particles, which is 75 microns or less [8]. It is possible for marble waste concrete to continue to acquire strength over time because of the extra binder generated by the interaction of marble waste with accessible lime. Aside from that, marble waste is the filler material because of its finesse, as it may be used as a micro-filler in cement aggregate matrix to produce dense concrete [52]. Higher dosages (30 percent) make the compaction process more difficult since the material lacks flowability, resulting in porous concrete with reduced strength.

Figure 9 Split Tensile Strength

As for coconut fibers (CFs), similar to the compressive strength split, tensile strength was also enhanced as the proportion of CFs rose up to 2.0 percent and subsequently decreased, as shown in Figure 9. When comparing the split tensile strength of 2.0 percent CFs to blank or reference concrete after 28 days of curing, the greatest split tensile was achieved at 2.0 percent CFs dose. It has also been observed that the addition of 2.0 percent fibers by volume may increase the tensile strength of concrete by around 40% [53]. The strength, however, was decreased when the 2.0 percent dose was exceeded. In concrete, fibers are used to improve the flexibility of the concrete by delaying the appearance of tension fractures or avoiding the formation of cracks in such a way that the tensile strength of (SFRC) steel fiber reinforced concrete is greater to that of ordinary concrete. Fibers have a crack-stopping effect rather than a crack-prevention effect. It is important to note that CFs have a greater impact on tensile strength than they do on compressive strength when compared to other materials. Several studies have shown that fibers increase the tensile capacity of post-cracking behavior [54]. Fibers have been found to have more substantial impacts on flexural tensile strength at volume fractions ranging from 0.5 to 2.0 percent, which were involved in this study [55].

As previously stated, split tensile strength exhibits the same pattern as compressive strength in a split configuration. As a result, there was a significant correlation between compressive and split strength. A regression model with an R^2 higher than 90 percent, as illustrated in Figure 10.

Figure 10 Co - Relation Between Compressive and Split Tensile Strength

As illustrated in Figure 11, a relative analysis is also performed in which the 28-day split tensile strength of the control mix is taken into account as the reference mix, and from there, various mixes with varied percentages of marble waste and coconut fiber are compared. At 20 percent and 2.0 percent replacement

of marble waste and Coconut fiber, split tensile strength is about 32 percent and 28 percent lower than when compared to the control (28 days) at 7 days curing, correspondingly, with the comparison of control. At 14 days curing, the split tensile strength of concrete is only 19 percent and 24 percent lower than that of reference concrete/control (28 days) when marble waste and coconut fiber is substituted at 20 percent and 2.0 percent of the total mix, respectively. When using 20 percent and 2.0 percent replacement of marble waste and coconut fiber, respectively, the split tensile strength of the concrete is 17 percent and 21 percent greater than the reference concrete after 28 days of curing, respectively.

Figure 11 Relative Analysis of Tensile Strength

The optimal dosage of marble waste (MW) and coconut fibers (CFs) for split tensile strength in SCC is determined by selecting 18 percent marble waste (MW) and 1.8 percent coconut fibers (CFs) from the contour plot that gives split tensile strength of 10 Mpa, as displayed in Figure 12 and Figure 13 . As part of the validation process for the estimated value of statistical models regarding split tensile strength of concrete, a comparable dose of 18 percent (MW) and 1.8 percent (CFs) of the concrete is cast and experimentally tested in the laboratory on about the similar days. It may be observed that the experimental value was very near to the anticipated value, indicating that the response surface models were correctly computed.

Figure 12 3D Response Surface for Split Tensile Strength

Figure 13 Contour Plot for Split Tensile Strength

3.2.3 Flexure Strength

Flexural strength, also known as bend strength or modulus of rupture, is a material property that may be specified as the stress in a material immediately before it fails in a flexure test [56]. Flexure tests were performed on beam specimens with dimensions of 150 x 150 x 500mm at 7, 14 and 28 days curing.

Figure 14 depicts the flexural strength of marble waste and coconut fibers at various doses. Flexure strength rise in a similar way to compressive strength as the proportion of marble waste climbed up to 20 percent replacement and then dropped progressively, similar to compressive strength. The greatest Flexure strength was achieved with a 20 percent substitution of marble waste, and the lowest Flexure strength was achieved with a 0 percent replacement of marble waste, as compared to reference concrete (blank mix). It has also been observed that the inclusion of marble powder increases the flexure strength of the concrete [8]. It is due to pozzolanic reaction of marble waste. The pozzolanic reaction of SiO_2 in marble waste with CH of cement results in the formation of extra cementitious compounds (C-S-H), which has a beneficial impact on flexure strength [44]. Increased dosages of marble waste (more than 20 percent by weight of cement) result in a reduction in strength owing to dilution effect, which cause to an alkali-silica reaction due to a greater amount of unreactive silica accessible due to the increased quantity of marble waste used in the mix. A greater dose also makes the curing process more problematic owing to a lack of workability, which results in porous concrete with a lower strength [45].

Considering Coconut fiber (CFs), flexure strength rises as the proportion of Coconut fiber grew up to 2.0 percent and subsequently dropped, as shown in Figure 14. It has been claimed that the flexure strength may be enhanced by as much as up to 2.0 percent fiber is added [46]. When flexure strength was measured after 28 days of curing, the greatest value was achieved with a 2.0 percent dose of Coconut fiber when compared to blank or reference concrete. The strength, however, was decreased when the CFs exceed 2.0 percent dose. The confinement of the fiber reinforcement on the specimen has a beneficial impact on flexure strength. Compression causes lateral expansion, which results in tension and shear as a result of the expansion. The fibers are able to withstand tension and shear due to their strength. This confinement has the potential to decrease the specimen's transverse deformation while simultaneously increasing its flexural strength. When the percentage of coconut fiber is increased, particularly at a greater dose, the process of compaction becomes more difficult, resulting in porous concrete and a reduction in flexural strength, as previously stated. It has been observed that increasing the flexure strength by up to 1.5 percent of the total volume of fibers increases it from 20 percent to 25 percent [47]. Steel fibers, at a concentration of 1.0 percent by volume, produce a significant increase in both the early and long-term strength of concrete. The highest increase in 28-day strength was found to be 29.15 percent with the maximum increase being 29.15 percent [48].

Figure 14 Flexure Strength

Figure 15 depicts the relationship between compressive strength and flexural strength when waste marble and coconut fiber is included into the concrete. This study found a significant co-relation between compressive and flexural strength, with an R^2 of more than 90 percent.

Figure 15 Co - Relation Between Compressive and Flexure Strength

Additionally, a comparison (relative analysis) is carried out, in which the 28-day flexure strength of control mix is taken into consideration as the reference mix, from which various mixes with varied percentages of marble waste and Coconut fiber are compare, as shown in Figure 16. At 20 percent and 2.0 percent replacement of marble waste and Coconut fiber, flexure strength is about 20 percent and 15 percent less than the control (28 days) at 7 days curing, respectively. Concrete flexure strength is only 8.0 percent and 4.0 percent greater than reference concrete/control (28 days) at 20 percent and 2.0 percent, respectively, after 14 days of curing. Concrete flexure strength is only 19 percent and 22 percent greater than reference concrete/control (28 days) at 20 percent and 2.0 percent, respectively, after 28 days of curing.

Figure 16 Relative Analysis of Flexure Strength

Figure 17 and Figure 18 illustrates the selection of 18 percent marble waste and 1.8 percent Coconut fiber from the contour plot, which results in a flexure strength of 6.5 Mpa (at 28 days), and is utilized to determine the optimal dose of marble waste and Coconut fiber for flexure strength in SCC. To validate the calculated value of statistical models for flexure strength of concrete, a similar dosage of 18% (MW) and 1.8% (CFs) are cast and experimentally tested in the laboratory on the same days. It can be observed that that the experimental value closely agreed with the predicted value, which validates the calculated response surface models.

Figure 17 3D Response Surface for Flexure Strength

Figure 18 Contour Plot for Flexure Strength

3.2.4 Pull Out/Bond Strength

Pull out the test was carried out on a cube of size 150mm to determine bond strength between concrete with reinforcing bar and could be performed according to ASTM C-234 [39]. For this test, the #4 bar is kept 100mm from the top as shown in Figure 19, of the mold before filling the concrete in the mold.

Figure 19 Pull out Test Sample Details

Bond strength with varying dosages of marble waste was presented in Figure 20. Bond strength is opposition offers by the surrounding concrete to pull out reinforced from the concrete cube into a certain depth. Like compressive strength, Bond strength is also increased as the percentage of marble waste increased up to 20% in substitution and then decreased gradually. According to test observation, maximum Bond strength was obtained with 20% substitution of marble waste, and Bond strength was obtained with 0% substitution of marble waste (blank mix). It is due to the pozzolanic activity of marble [57] which gives dense mass, and the bond between reinforcement bar and surrounding concrete improved due to the confinement effect. Also, due to its finesse, marble waste acts as a micro-filler in cement aggregate matrix which dense concrete leading to more force is required to pull out reinforcement of concrete [52]. It has been also reported that bond strength mainly depends on the strength of surrounding concrete i-e before pulling reinforcement concrete laterally expands [58]. By using marble waste, more force is required to expand concrete laterally which results in more bond strength. However, at a higher dosage of marble waste (beyond 20 % by weight of cement) strength reduces due to dilution effect which leads to alkali-silica reaction due to higher quantity of unreactive silica available due to high quantity of marble waste. Also, at a higher dosage, the compaction process become more difficult due to lack of workability which results in porous concrete, leading to lower strength [45].

As for Coconut fiber concerns, bond strength improved as the percentage of Coconut fiber (CFs) enhance up to 2.0 percent and then decreased as displayed in Figure 20. After 28 days of curing, the maximum bond strength was achieved at 2.0 percent dosage of Coconut fiber as in comparison to the control concrete. However, beyond the 2.0 percent dosage, the strength was gradually decreased. The improvement in bond strength is because to the confinement of the coconut fiber around the cylindrical sample. This confinement of CFs can reduce transversal deformation of the specimen. Bond strength mainly depends on the strength of surrounding concrete i-e before pulling reinforcement concrete laterally expands [58]. By using fibers, more force is required to expand concrete laterally as fiber prevents propagation of cracks which results in

more bond strength. However, at a higher dosage, the compaction process becomes more difficult due to lack of workability which results in porous concrete, leading to lower concrete strength leading to less force is required to pull out reinforcement from concrete.

Figure 20 Pull Out/Bond Strength Results

The correlation between compressive strength and bond strength with the incorporation of waste marble is shown in Figure 21. It can be observed from the regression model that a strong co-relation was existing in between compressive and bond strength having R^2 greater than 90%.

A relative analysis is also performed in which the 28-day bond strength of the control mix is taken into account as the reference mix as shown in Figure 22, and various mixes with varied percentages of marble waste and coconut fiber are compared. At 20 percent and 2.0 percent replacement of marble waste and Coconut fiber, bond strength is about 29 percent and 24 percent lower than when compared to the control (28 days) at 7 days curing, correspondingly, with the comparison of control. At 14 days curing, the bond strength of concrete is only 15 percent and 12 percent lower than that of reference concrete/control (28 days) when marble waste and coconut fiber is substituted at 20 percent and 2.0 percent of the total mix, respectively. At 20 percent and 2.0 percent replacement of marble waste and coconut fiber, the bond strength of the concrete is 20 percent and 22 percent greater than the reference concrete after 28 days of curing, respectively.

Figure 21 Co - Relation Between Compressive and Pull Out/Bond Strength Results

Figure 22 Relative Analysis of Pull Out/Bond Strength Results

To evaluate optimum dosage marble waste and Coconut fiber for bond strength in SCC, 18% marble waste and 1.8% Coconut fiber are selected from the contour plot giving flexure strength 5.0 Mpa (at 28 days) as shown in Figure 23 and Figure 24. To validate the calculated value of statistical models for bond strength of concrete, a similar dosage of 18% (MW) and 1.8% (CFs) are cast and experimentally tested in the laboratory on the same days. It can be observed that that the experimental value comparable with the

predicted value, which validates the calculated response surface models.

Figure 23 3D Response Surface for Pull Out/Bond Strength

Figure 24 Contour Plot for Pull Out/Bond Strength

4 Conclusion

In this study, a step towards utilization of marble waste (from 0% to 30% by weight of cement) and coconut fibers (from 0% to 3.0% by weight of cement) has been made in the manufacturing of sustainable self-fiber compacting concrete. The following conclusion has been drawn based on experimental work:

- When the proportion of marble waste (Mw) and coconut fibers (CFs) is raised, the flowability and passing ability of the concrete decreased. However, all the mixes, except for the 2.5 percent and 3.0 percent CFs, demonstrate excellent filling and passing capabilities within the limits specified by the practical requirement for SCC.
- Mechanical performance improved as the proportion of Mw was increase up to 20 percent addition and then reduce as compared to the reference concrete. It is because of micro-filling voids in concrete ingredients as well as pozzolanic reaction of Mw.
- Coconut fibers (CFs) improved mechanical performance up to 2.0 percent addition by weight of cement and then declines gradually as compared to the reference concrete. The positive influence on mechanical performance is because of confinement coconut fibers (CFs) around the sample. However, at higher dosage (beyond 2.0% substitution), the compaction of concrete become more difficult due lack flowability, resulting pore in harden concrete which decreased mechanical performance od SCC.
- Based on work results, the predicted value from statistical analysis and the experimental value were comparable.
- The maximum mechanical performance was achieved at the substitution ratio of 18 percent Mw and 1.8 percent CFs respectively, having a maximum compressive strength of 23 Mpa which was almost 37 percent greater than from control mix. Hence 18 percent marble waste (Mw) and 1.8 percent coconut fibers (CFs) were optimal dosage for combined substitution.

Finally, the current research indicates that marble wastes and coconut fibers (CFs) are excellent, abundant, local eco-materials that are low-cost and may be utilized for SCC manufacturing when viewed from the viewpoint of both economic and environmental limitations.

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