



SYNERGISTIC EFFECT OF SUGARCANE BAGASSE ASH AND MARBLE SLUDGE POWDER AS A PARTIAL REPLACEMENT OF CEMENT IN CONCRETE

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Abstract

Marble sludge powder is produced as a by-product during the cutting and polishing of marble. Similarly, sugarcane bagasse ash is produced during the burning operation of sugarcane bagasse. Improper disposal of these waste materials poses a severe threat to the environment. The objective of this research study was to partially substitute cement with a binary mixture of SBA and MSP to reduce the environmental and health issues by adequately utilizing the waste material in the production of low-cost and eco-friendly concrete. For this purpose, a total of 174 concrete cylinders were tested. Apart from this, XRF and EDX tests were performed to determine the chemical composition of waste. Ordinary Portland cement was replaced with a binary mix of SBA and MSP from 0 to 40% by weight to achieve the synergistic effect. Various tests were performed, including compressive and splitting tensile strength and material tests, i.e. specific gravity, absorption capacity, sieve analysis, dry rodded unit weight, and moisture content. The tested specimens were

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compared with the control samples. The results showed that the difference between compressive and tensile strength up to 15% replacement is within targeted strength and slump. The optimized sample by partial substitution with a negligible effect on properties of concrete was SB10-MP5 and SB5-MP10. The increase in partial replacement above 15% will lead to a decrease in compressive and tensile strength. The cost per cubic meter of concrete was reduced by 8% as per MRS2019.

Keywords: Sugarcane bagasse ash, marble sludge powder, EDX, XRF

Nomenclature

MSP	Marble Sludge Powder	SBA	Sugarcane Bagasse Ash
SB5	5% Sugarcane Bagasse Ash	MP10	10% Marble Sludge Powder
EDX	Energy-dispersive X-ray spectroscopy	XRF	X-ray Efflorescence
OPC	Ordinary Portland Cement	MRS	Market Rates Schedule
NASA	National Aeronautics and Space Administration		

I. Introduction

Concrete is a fundamental building construction material that plays a significant role in the infrastructure and economic development of a country. The consumption rate of concrete had increased worldwide and reached about 25 billion tons per year [XXVIII]. The annual production of Cement as a main constituent of concrete exceeds about 4.1 billion tons [XI]. The cement industry alone is accountable for approximately 5% of universal anthropogenic CO₂ release. The production of one ton of cement produces around one ton of carbon dioxide gas [XV]. These emissions of CO₂ are mainly due to the calcination and grinding of clinker during the production of cement [VIII]. The emission of CO₂ in huge amounts gain the attention of researchers to use alternative materials for cement. Different researchers used industrial and agro-waste as an alternative because of their sustainable and mechanical properties. The commonly used alternative pozzolanic materials are rice husk ash [XVI, XII, IX], silica fume [XXVI, XXI], blast furnace slag [XXVI], wheat straw ash [XIX], MSP [XVIII, XXV], and SBA [XX, VII, X]. SB is a fibrous material used as a source of fuel for generating power in sugar mills and the burning results in the production of inert ash called SBA. According to Jagadesh et al. [X], approximately 62 kg of SBA is produced from one ton of crushed sugarcane. The presence of a high amount of silica makes it a good partial substitute for cement. Several researchers [XXII, IX, XII] have found that the use of SBA as a partial replacement of OPC can improve the durability and mechanical properties of concrete. Tekle [XXIV] replaced cement with 10% SBA and the results showed an increase in the compressive strength of concrete. Jagadesh et al. [X] substituted OPC up-to 30% and the results showed a 28% enhancement in the compressive strength at 10% replacement of SBA. Besides agriculture waste, several industrial wastes such as MSP could also be utilized as supplementary cementitious material in concrete and mortar.

Marble has been significantly utilized for construction and decorative purposes [XIII]. MSP is obtained as a by-product during the sawing and polishing process of marble stone and approximately 20-30% of it turns into waste [III]

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[XXV]. MSP is an inert material, and its improper disposal causes severe ecological problems, including water and land pollution [IV]. In order to abridge the harmful effects of MSP, several researchers highlighted its practical usage as a partial substitute of cement and sand in concrete [XVIII, XXV, IV, V, VI, XXIII]. Ulubeyli and Artir [XXV] utilized 5-10% MSP as an alternative material for aggregates in concrete and get positive results. Omar et al. [XVIII] studied the behavior of concrete by replacing cement with MSP and recorded an increase of 5%, 16%, and 20%. Corinaldesi et al. [IV] also partially replaced cement with MSP in different proportions and the results showed that replacement up to 10% indicates a significant improvement in compressive strength and durability. Singh et al. [XXIII] studied the long-term effect of MSP in concrete and replaced up to 25%. The results indicated that up to 15% replacement enhanced the physico-mechanical properties of concrete.

SBA and MSP contain a high amount of silica and calcium-based materials, respectively. These pozzolanas and calcium-based materials, in the presence of water chemically combine with the free lime, and produce a cementitious material. During the hydration of OPC the principal silicates (C_3S and C_2S) and aluminate (C_3A), present mostly in the crystalline form, react with water to provide desired silica and alumina form cementitious compounds. Hence, while evaluating the suitability of mineral admixtures for cement, their mineralogical composition should be considered together with the chemical composition. Since the composition of SBA and MSP separately does not match with that OPC. Therefore, a combination of different percentage mixes of SBA and MSP were carefully and intelligently designed to achieve the synergistic effect of SBA and MSP compatible with the cement. Therefore, this study aimed to partially substitute the OPC with the binary mix of SBA and MSP, without affecting the mechanical properties of concrete, and to sort out the best-optimized mix. For this purpose, cement was replaced by SBA and MSP up to 40% by weight. Microstructural analyses were carried out to obtain the chemical properties of each waste. Compressive and tensile strength tests were also carried out to determine the mechanical properties of the concrete specimens. The partial replacement of SBA and MSP with OPC could reduce the cost of concrete. As a result of this research study, a reduction in unit rate cost of concrete was achieved along with the gainful utilization of waste, which is useful, feasible, and remarkable for a green environment and developing countries.

II. Materials and Methods

The SBA and MSP were collected from the local industry. The material tests on cement, natural aggregates, SBA, and MSP, were performed as per the standard procedure of ASTM. The different mixes of these two-industrial wastes were used as a partial cement substitute in different percentages. The different series of concrete specimens contain 0, 10, 15, 20, 25, 30, 35, and 40% by weight of cement. The control specimen having a 0% replacement was used as a reference. Various tests were performed, i.e., slump test by Abram's cone, compressive and splitting tensile strength at 28th days. The results of the control and the rest of the samples were compared for the optimized mix.

Fine Aggregate

The properties of sand were determined for the mix designing of concrete. The results as shown in Table 1, indicate that dry rodded unit weight is 1.64 gm/cc as per ASTM C-29. The fineness modulus is 2.91 as per ASTM C-136, which is said to be coarse sand. The specific gravity is 2.75, which is in the range as per ASTM C-127. The absorption capacity is 1.51%, and the moisture content was found out to be 3.24% as per ASTM C-128.

Table 1. Fine aggregate Properties

Test Description	Values
Dry Rodded Unit weight	1.64 gm/cc
Fineness Modulus	2.91
Specific gravity	2.75
Absorption Capacity	1.51%
Moisture Content	3.24%

The graph shows that D10 is 0.2 mm, D30 is 0.5 mm, and D60 is 0.9 mm. The Cu is calculated to be 4.1, which is higher than 4. The Cc is estimated to be 1.1, which is in the range of 1-3. The Cu and Cc values indicate that the sand is well-graded, as shown in Figure 1.

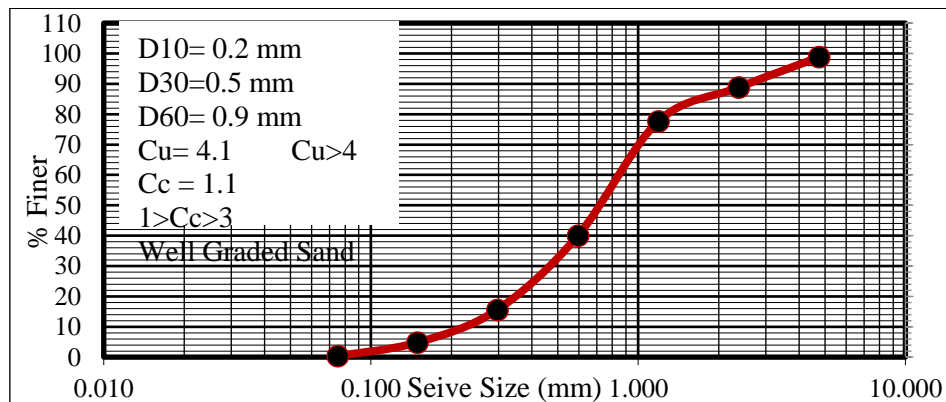


Fig. 1. Sieve analysis of Sand

Coarse Aggregate

The properties of the crush found out for mix designing of concrete, as shown in Table 2. The result indicates that dry rodded unit weight is 1.56 gm/cc, which is less compact as compared to sand as per ASTM C-29. The maximum size of aggregate was found out to be 3/4" as per ASTM C-136, which is mostly used in concrete for buildings and roads. The specific gravity is 2.72, which is in the range as per ASTM C-127. The absorption capacity is 0.60%, and the moisture content was found out to be 0.15% as per ASTM C-128.

Table 2. Coarse aggregate Properties

Test Description	Values
Dry Rodded Unit weight	1.56 gm/cc
Fineness Modulus	2.91
Specific gravity	2.72
Absorption Capacity	0.60%
Moisture Content	0.15%

The graph shows that D10 was 2.6 mm, D30 was 9.3 mm, and D60 was 13.5 mm. The Cu was 5.3, which is higher than 4. The Cc was calculated to be 2.5, which was in the range of 1-3. The Cu and Cc values show that the sand was well-graded coarse aggregate, as shown in Figure 2.

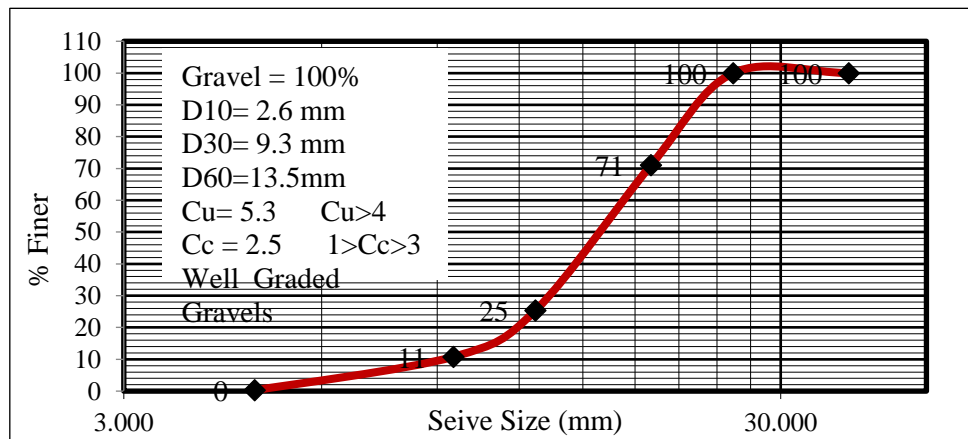


Fig. 2. Sieve analysis of coarse aggregate

Concrete Mix Design

The mix designing for concrete was carried out for the targeted strength of 3000psi and targeted slump ranging from 2" to 3" as per ACI 211.1-91 for one cubic yard. The water and air content were taken from Table 6.3.3 of ACI 211.1. The water to cement ratio was taken from Table 6.3.4(a) of ACI 211.1, and the weight of cement was calculated. The percentage factor for coarse aggregates was taken from Table 6.3.6 of ACI 211.1, and the weight of coarse aggregate was calculated. The volume of fine aggregate was found out by the absolute volume method. The moisture adjustment was carried out by the addition of absorption capacity and subtraction of moisture content of all material, i.e., MSP, SBA, fine aggregate, and coarse aggregate. The final composition of cement, fine aggregate, and coarse aggregate with water to cement ratio is shown in Table 3.

Table 3. Mix Design Ratios

Description	Values
Ratio by weight	1: 2.65: 2.79
Ratio by volume	1: 3.03: 3.22
Water/Cement ratio	0.57

Specimen Preparations

In addition to control samples, various samples, including 0% to 40%, of a binary mix of SBA and MSP were prepared, as shown in Figure 3. A total of 174 cylinder samples having the dimension of 150 mm x 300 mm were fabricated, according to ACI 211.1-91, in which 87 cylinders were fabricated for compressive strength test, and the rest of 87 specimens were prepared for splitting tensile strength test. For the preparation of samples, the required coarse aggregate, fine aggregate, SBA, MSP, cement, and water were weighed and thoroughly mixed to find out slump by Abram's cone for each sample as per ASTM C-39. All specimens were placed in saturated lime water for 28 days curing as per ASTM C192.

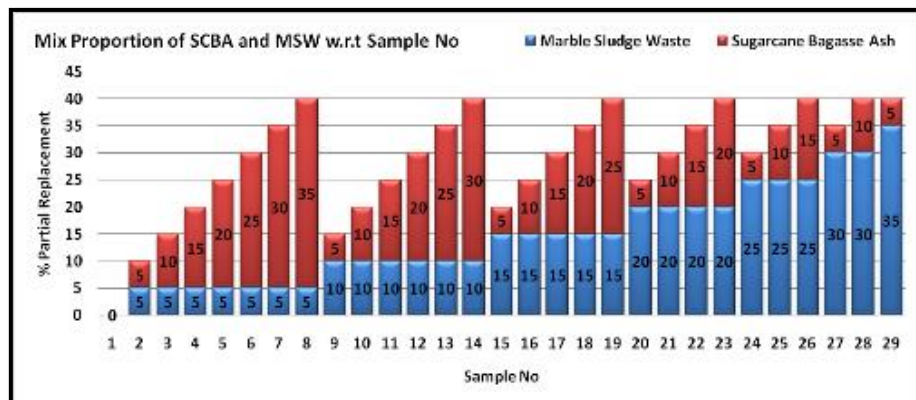


Fig. 3. Mix proportion of SBA and MSP with OPC in concrete

Instrumentation and Devices

The microstructural analysis of SBA and MSP was determined by EDX and XRF analysis. The EDX and XRF analysis were performed by EDX-7000 with air as the atmosphere. The compressive and splitting tensile test was performed by the Universal Testing Machine, having a capacity of 200 tons.

Specimen Testing Procedure

The slump test was conducted on each sample batch according to ASTM C-39. The compressive test was carried out by Universal Testing Machine (UTM) for 87 cylinders, according to ASTM C-36. The Splitting tensile strength test was performed for the rest of 87 specimens according to ASTM C-496. The peak load value was recorded for each cylinder. The average value was found out from three specimens of each sample batch.

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III. Results and Discussion

XRF Analysis of MSP

The XRF analyses of MSP was carried out to determine the elemental and oxide composition. The XRF analysis indicated that calcium in elemental form was the main mineral component in Marble Sludge Powder. The fundamental elemental composition of Marble Sludge Powder was Ca (99.46%), and other elements, i.e., Iron (Fe), Strontium (Sr), Copper (Cu), Nickel (Ni) were also present as shown in Table 4. Omar et al. [XVIII] studied the chemical composition of MSP and stated that it has high contents of calcium, nearly 97%.

Table 4. XRF analysis on Marble Sludge powder for elements

Analyte/ Element	Results (%)
Calcium (Ca)	99.46
Iron (Fe)	0.37
Strontium (Sr)	0.09
Copper (Cu)	0.06
Nickel (Ni)	0.02

The XRF analysis also showed that calcite in oxide form was the primary mineral component in Marble Sludge Powder. The oxide composition of MSP was CaO (99.55%), and other oxides, i.e., Iron oxide (Fe_2O_3), Strontium Oxide (SrO), Copper oxide (CuO), Nickel oxide (NiO) were also present as shown in Table 5.

Table 5. XRF analysis of Marble Sludge powder for oxides

Analyte/ Oxides	Results (%)
Calcium oxide (CaO)	99.55
Iron Oxide (Fe_2O_3)	0.32
Strontium Oxide (SrO)	0.07
Copper Oxide (CuO)	0.05
Nickel Oxide (NiO)	0.03

EDX Analysis of MSP

In the EDX spectrum, the Y-axis depicts the number of counts, and the x-axis represents the energy of the X-rays. The position of the peaks leads to the identification of the elements, and the peak height helps in the quantification of each element's concentration in the sample, as shown in Figure 4. The calcium percentage in the MSP sample is 99.46%. The result also indicates the presence of other elements, i.e., Si, C, O, and Mg.

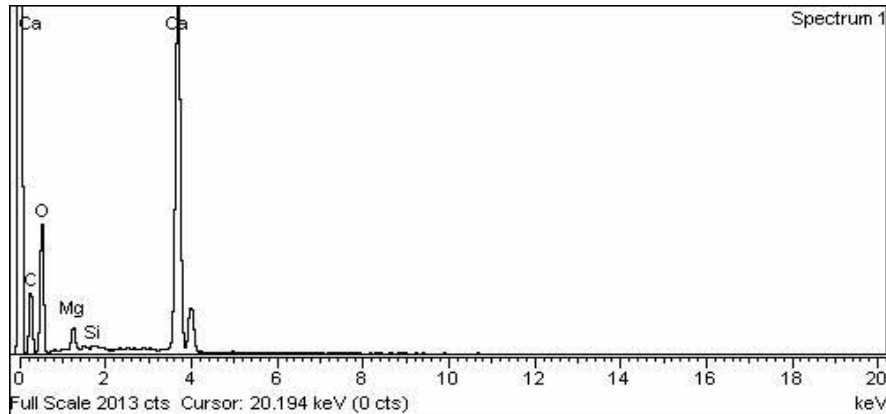


Fig. 4. EDX analysis results of Marble Sludge Powder

XRF Analysis of SBA

The XRF analyses of SBA were carried out to determine the elemental and oxide composition. The XRF analysis indicated that silica in elemental form was the key component in SBA. The silica (Si) was 63.39%, Calcium (Ca) was 14.95%, Potassium (K) 13.32%, Iron (Fe) was 5.40%. The other elements, i.e., Phosphorus (P), Sulfur (S), Titanium (Ti), Manganese (Mn), Copper (Cu), Strontium (Sr), Zinc (Zn), Rubidium (Rb), Zirconium (Zr) were also present as shown in Table 6.

Table 6. XRF analysis of Sugarcane Bagasse Ash for elements

Analyte/ Element	Results (%)
Silica (Si)	63.39
Calcium (Ca)	14.95
Potassium (K)	13.32
Iron (Fe)	5.40
Phosphorus (P)	1.14
Sulphur (S)	0.56
Titanium (Ti)	0.47
Manganese (Mn)	0.36
Copper (Cu)	0.13
Strontium (Sr)	0.13
Zinc (Zn)	0.09
Rubidium (Rb)	0.03
Zirconium (Zr)	0.02

The XRF analysis indicated that quartz in oxide form was the prime mineral component in SBA. The silicon dioxide (SiO_2) was 81.02%, Calcium oxide (CaO) was 8.21%, Potassium oxide (K_2O) was 6.96% and the other oxides, i.e., Iron oxide (Fe_2O_3), Sulfur trioxide (SO_3), Titanium dioxide (TiO_2), Manganese oxide (MnO), Copper oxide (CuO), Strontium oxide (SrO), Zinc oxide (ZnO), Rubidium oxide (Rb_2O), Zirconium oxide (ZrO_2) were also present as shown in Table 7.

Table 7. XRF analysis of Sugarcane Bagasse Ash for oxides

Analyte/ Oxides	Results (%)
Silicon Dioxide (SiO_2)	81.02
Calcium oxide (CaO)	8.21
Potassium oxide (K_2O)	6.96
Iron oxide (Fe_2O_3)	2.65
Sulfur trioxide (SO_3)	0.54
Titanium dioxide (TiO_2)	0.29
Manganese oxide (MnO)	0.16
Copper oxide (CuO)	0.06
Strontium oxide (SrO)	0.05
Zinc oxide (ZnO)	0.04
Rubidium oxide (Rb_2O)	0.01
Zirconium oxide (ZrO_2)	0.005

EDX Analysis of SBA

In the EDX spectrum, the Y-axis depicts the number of counts, and X-axis represents the energy of the X-rays. The position of the peaks leads to the identification of the elements, and the peak height helps in the quantification of each element's concentration in the sample, as shown in Figure 5. (1 keV=1.6e-16 Joules). The silica percentage in the SBA sample was 63.39%. The results also showed the presence of other elements, i.e., Ca, C, O, Mg, Na, Al, P, S, N, and K.

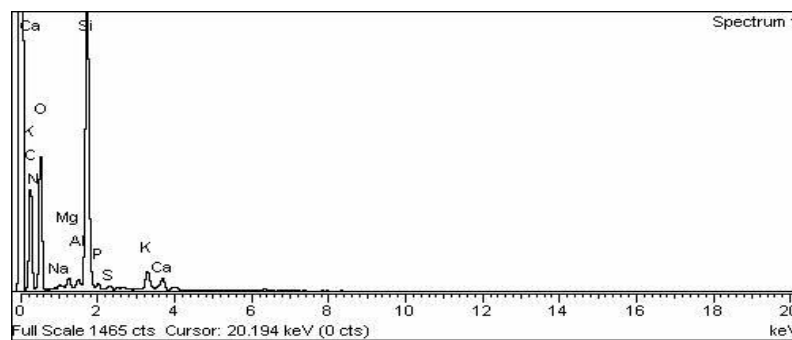


Fig. 5. EDX analysis results of Sugarcane Bagasse Ash

Results of Compressive and Tensile Testing

Three specimens for each group was tested under uniaxial compressive loads. The test results are shown in Table 8, which shows that the difference between compressive and tensile strength up to 15% replacement was within the targeted

strength and slump. However, the compressive and tensile strength decreases significantly with the addition of SBA and MSP beyond 15% of the total weight. Moreover, a significant drop was observed in the slump for the replacement level of 35-40%. This drop in the slump was due to the increase of the fine particles in the shape of MSP and SBA, therefore increasing the surface area and water absorption by the concrete mix. This phenomenon was also reported by Khan and Ganesh [XIV]. Also, similar behaviour was previously observed by Mangi et al. [XVII]. The optimized sample by partial substitution with a negligible effect on properties of concrete was sample SB5-MP5 or SB5-MP5. The increase in partial replacement above 15% leads to a decrease in compressive and tensile strength of concrete. Due to the presence of a hybrid matrix, it was unable to complete a proper pozzolanic reaction for the formation of C-H-S gel in the concrete mix at a curing period of 28 days. Moreover, the compressive and tensile strength of the concrete matrix increases slowly due to the presence of MSP. It is because of the higher percentage of C_2S , which hydrates very slowly as reported by Khan et al. [XIII], and there is the possibility of the strength enhancement at a longer curing time and age [XXVII]. The replacement level of the cement with a binary mix of SBA and MSP has many benefits, such as reducing the emission of CO_2 , utilization of waste, and the overall cost of concrete. Furthermore, the concrete containing the binary mix could be used in hot weather conditions where a slow hydration reaction is required. The test results are in agreement with the previous studies performed on the partial replacement of MSP and SBA as individual substituting material [XVIII, XXV, IV, V, VI, XXIII].

Table 8. Compressive and tensile strength of concrete with partial replacement of cement with a binary mixture of SCBA and MSP

Sample No	% Partial Replacement	Compressive Strength (psi)	Splitting Tensile Strength (psi)	Slump (in)
Control	0	3508	309.3	2.2
SB5-MP5	10	3494	307	2.2
SB10-MP5	15	3045	271.3	2.1
SB15-MP5	20	2547	220.7	1.9
SB20-MP5	25	1750	151.3	1.7
SB25-MP5	30	1210	105	1.1
SB30-MP5	35	996	85.8	0.8
SB35-MP5	40	719	62.3	0.7
SB5-MP10	15	3094	283.3	2.1
SB10-MP10	20	2399	207.5	1.7
SB15-MP10	25	1859	160.9	1.3
SB20-MP10	30	1421	122.8	1.1
SB25-MP10	35	1186	103.2	0.9
SB30-MP10	40	937	81.1	0.8
SB5-MP15	20	2382	206.2	2.3
SB10-MP15	25	1621	140.5	2
SB15-MP15	30	1354	117.3	1.9
SB20-MP15	35	1038	90.3	1.8
SB25-MP15	40	765	66.4	1.7
SB5-MP20	25	2105	182.1	2.5
SB10-MP20	30	1386	120	2.3

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SB15-MP20	35	1098	94.8	2
SB20-MP20	40	856	74.2	1.3
SB5-MP25	30	1477	127.9	2.9
SB10-MP25	35	1186	102.5	2
SB15-MP25	40	887	76.7	1.3
SB5-MP30	35	1245	108.1	2.8
SB10-MP30	40	986	85.3	1.9
SB5-MP35	40	1105	95.5	2.5

Graph of Sample No vs. Compressive strength of Specimens

The blue bar graph was drawn between the cylinder compressive strength (psi) and with the serial no of the cylinder sample, as shown in Figure 6. It shows that as the amount of waste as partial replacement material increases, the compressive strength decreases. The compressive strength data best fitted the polynomial curve of 3rd degree with the precision of about 99.2% with a black line, as shown in Figure 6. The following Eq. (1) can be used for defining the compressive strength data.

$$Y = -0.215x^3 + 14.22x^2 - 344.3x + 4019 \quad (1)$$

R²-factor = 0.992

The white color bars show the percentage replacement of MSP, and the black color bars show the percentage replacement of SBA

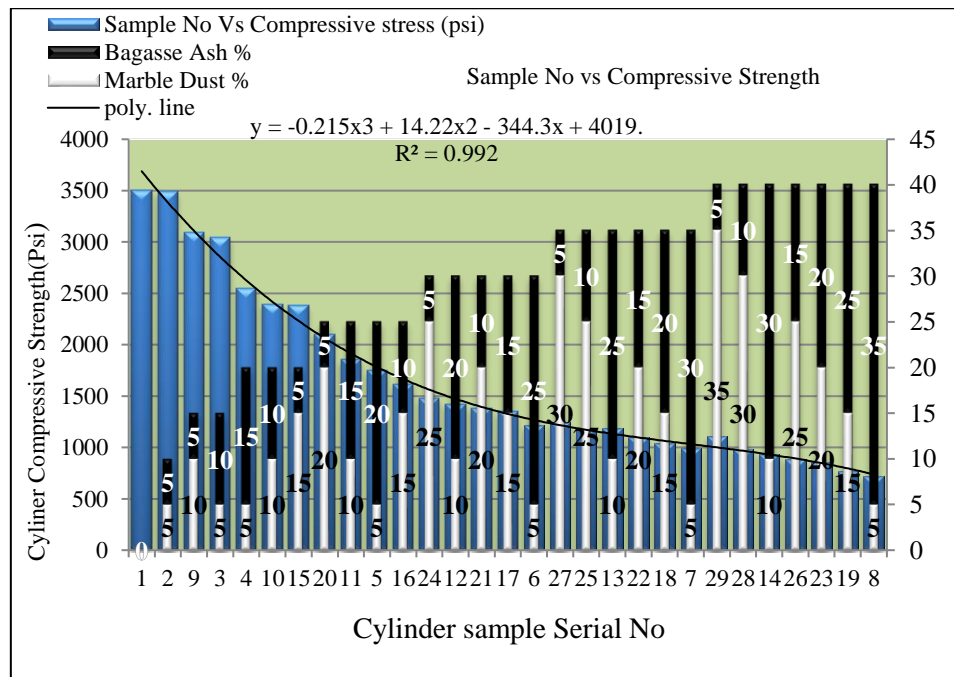


Fig. 6. Sample No vs. Compressive Strength

Graph of Sample No. vs. Tensile Strength of Specimens

The green colour bar graph was drawn between the cylinder splitting tensile strength (psi) and with the serial no of the cylinder sample, as shown in Figure 7. It shows that as the amount of waste as partial replacement material increases, the splitting tensile strength decreases. The splitting tensile strength data best fitted the polynomial curve of 3rd degree with the precision of about 99% with a black line, as shown in Figure 7. The following Eq. (2) could be used for defining the splitting tensile strength data

$$Y = -0.020x^3 + 1.337x^2 - 31.72x + 358.4 \quad (2)$$

R^2 -factor = 0.990

The white colour bars show the percentage replacement of Marble Sludge Powder, and the black colour bars show the percentage replacement of Sugarcane Bagasse Ash.

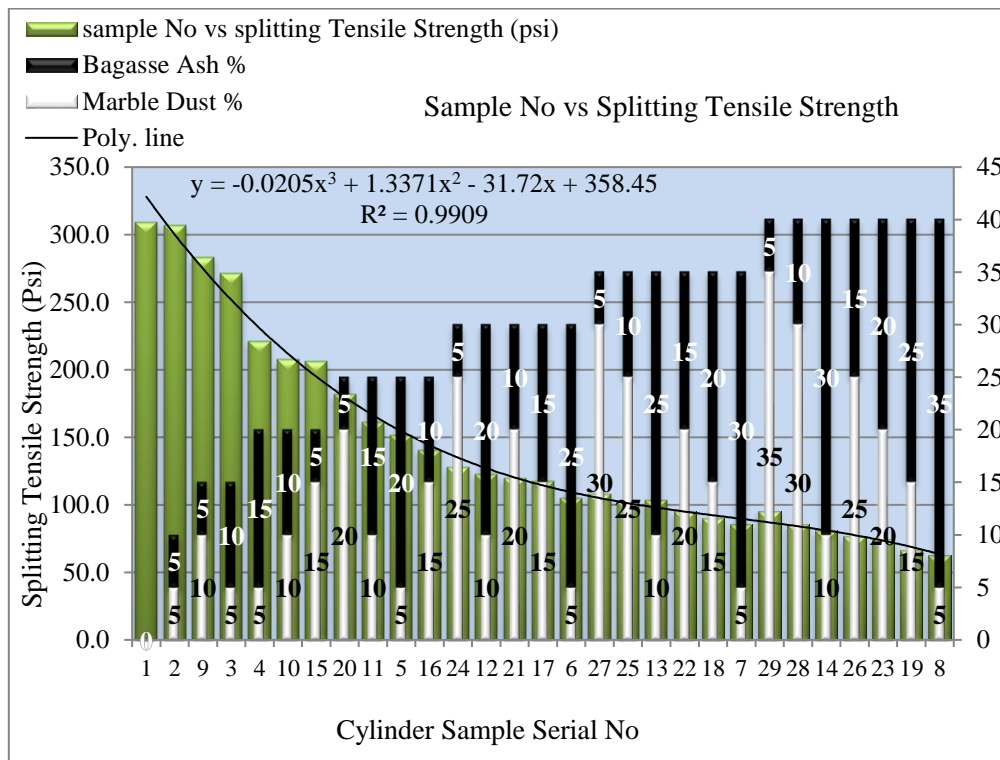


Fig. 7. Sample No vs. splitting tensile Strength

IV. Cost Analysis

The waste was incorporated in rate analysis of items, namely "RCC in roof slab, beam, column & other structural members, in-situ or precast (1:2:4) with item code 06-07-a-03 in Pakistan Market Rate System (MRS) 2019 as 15% partial replacement with cement. It was concluded that the unit rate cost of concrete per cubic meter was reduced by 8%.

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V. Conclusions

- I. The optimized sample with a negligible effect on the properties of concrete is SB10-MP5 and SB5-MP10.
- II. The increase in partial replacement of SBA and MSP by more than 15% will lead to a decrease in compressive and tensile strength of concrete.
- III. The same chemical composition of SBA and MSP can be used according to the defined equation and partial percentage replacement with cement in concrete.
- IV. The chemical composition shows that SBA has a high content of silica, and MSP has a high content of calcium, which makes both wastes as excellent cement substituting materials.

Conflict of Interest

There was no relevant conflict of interest regarding this paper.

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