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Road construction material in reference to: Response Surface Methodology-Based Evaluation of Construction Waste Aggregates

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ABSTRACT-Over the past ten years, a significant number of concrete waste aggregates (CWAs) have been produced by the process of expanding the road network throughout India. Inadequate efforts to create novel technologies that would increase the CWAs' reusability have accelerated their disposal in landfills or waterways. Thus, significant efforts were undertaken in this study to demonstrate the effective use of CWAs that had been pre-treated with bitumen emulsion in the creation of the roads' wearing coat (WC). To design the laboratory trials and create ideal conditions for generating sufficient road construction materials, two multivariate approaches—central composite design (CCD) and box-behnken design (BBD)—were employed. Numerous attributes of the lab specimen, such as volumetric properties, water resistance, and reaction parameters

KEYWORDS - Boxbehnken approach (BBD); Central composite design (CCD); concrete waste aggregates; sustainable development goals; waste management

1. INTRODUCTION

The investments made in a country's infrastructure development can be used to gauge its economic progress. However, a number of problems, including air, water, and noise pollution as well as the production of concrete waste aggregates (CWAs), are brought on by the activities that go into infrastructure development, such as building, demolition, and maintenance. The latter of these, the creation of CWAs, has a number of direct or indirect effects on the environment [1–3]. In mountainous areas, ineffective CWA management has resulted from difficult topography and a shortage of resources. Road building and upkeep are the key infrastructure development in these areas.

Unprecedented occurrences like earthquakes, landslides, excessive rainfall, and the dropping of large rocks and boulders occasionally cause ongoing damage to roads that have been built in hilly areas. As a result, roadways in these locations need to be maintained frequently, and this process generates a significant amount of CWAs. The CWAs produced in this manner are often disposed of in landfills, picked up from the side of the road, or thrown into adjacent bodies of water [4, 5].Such CWA management techniques may also result in other major problems like road congestion, river flow deviations, and effects on local flora and wildlife, all of which might eventually negatively affect downstream inhabitants' quality of life [6–8].

In dumping grounds, the CWAs occupy the space for municipal solid waste and consequently reduce their life. Therefore, considering several environmental impacts associated with management of the CWAs and global need of fulfilling the United Nation’s Sustainable Development Goals (SDGs) viz., SDG 3, SDG 8, SDG 12, SDG 13, it is imperative to find innovative ways of managing the CWAs generated during the infrastructure development in the mountainous region [9].

One of the promising ways, of managing the CWAs, that has become popular among civil engineers, is recycling and reusing them as a construction mate- rial [10, 11].Previous studies have also proven the applicability of the CWAs as an aggregate in manufacturing of concrete and also in construction of sub-base and base layers of the pavements [12–16]. However, construction material made using the CWAs show depreciated quality in their properties such as, low water resistance, decreased resistance to permanent deformation etc [17–21]. Therefore, civil engineers are suscep- tible about the usage of CWAs as a construction material. Several efforts are being made, among the researchers’ community such as, optimizing the proportion of the CWAs

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and pre-treatment with certain chemicals, to enhance the reusability of the CWAs. In this regard, the CWAs were reported to be pre-treated in different ways viz., heat, cement paste and liquid silicon resin.

In this study, efforts were made to analyse the reusability of the CWAs, generated from demolished roads in the Himalayan region of Himachal Pradesh, India. The ma- jor goal of this study is to use the CWAs as an aggregate material in construction of wearing coat (WC). With this objective, the CWAs were also treated with bitu- men emulsion so that the product could attain the desired volumetric and mechanical characteristics, as required for the construction of WC. Further, central composite design (CCD) and box-behnken design (BBD) in combination with response surface methodology (RSM) were used to optimize the concentration of the CWAs, bitumen binder and temperature. To the best of our knowledge, such studies are scanty and its findings may encourage the global auditory comprising scientific community and authorities to adopt the applicability of the bitumen-treated CWAs as an aggregate material in construction of roads.

2. MATERIALS AND METHODS

2.1 Preparing the raw materials

2.1.1 Aggregates

In present investigation, the CWAs and hornfels were used as aggregates. The CWAs were collected from the road repair and construction site on the Chandigarh to Manali highway in India. The location of the construction site is shown in Figure 1.

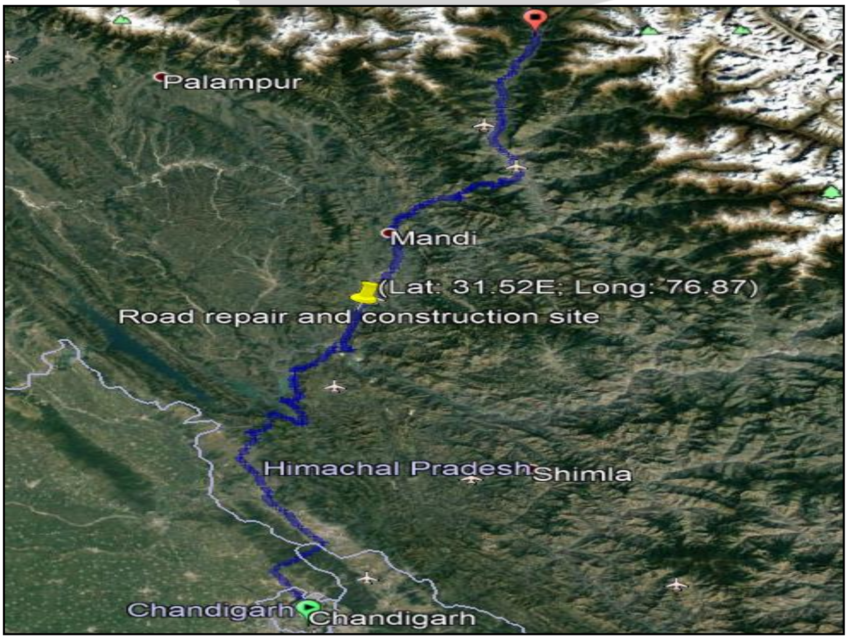

Fig. 1 Location of road repair and construction site

The construction site is located at 3450 ft above sea level (asl) and 20 kg of the CWAs were collected from the site and brought to the laboratory. It was observed that the CWAs were mainly composed of concrete and petrous material (91.2%). Rest of the composition (8.8%) comprised of the impurities or unwanted materials such as, wood, rubber or gypsum. As impurities may cause variations in the Marshall-based analysis and other tests, they were removed manually from the CWAs before using them for laboratory analysis. The hornfels, used as a natural aggregate, were facilitated by Punjab Engineering College, Chandigarh, India. Both types of the aggregates were further analysed using SEM/EDS. The findings of this analysis revealed that both CWAs and hornfels comprised of 61% and 63% of the siliceous content, respectively, which also depicted the inability of aggregates to resist damage caused by water. Further, morphological properties of both the types of the aggregates were also observed. Morphological characteristics of the aggregates based on MoRTH specifications and the conventional method of testing (as per IS codes) are described in Table 1.

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Table1. Aggregate characteristics based on conventional methods

Property (Standard)	Units	Natural Aggregates	CDW Aggregates	Treated CDW aggregates	Method of Test	Requirements (MoRTH_5th_Revision)/ (IS: 2386)
Crushing Value	In Percentage	16.25	39.23	32.33	IS: 2386 part4	(Max 30 % as per MoRTH)/ (Max 45% as per IS 2386 –Part 4)
Los Angeles Abrasion	In Percentage	24.66	43.10	38.22	IS: 2386	Max 35%
Aggregate impact	In Percentage	22.44	34.34	31.55	IS: 2386	Max 27%
Specific gravity	-	2.66	3.66	3.26	IS: 2386	2.5 – 3
Water absorption	In Percentage	1.65	2.65	2.25	IS: 2386 Part 3	Max 2%
Coating and stripping of bitumen aggregate mix	In Percentage	101	91	93	IS: 6241	Minimum retained coating 95 %
Angularity Number	-	8.66	12.22	11.2	IS: 2386 part I	7-10

From Table 1, it can be seen that the CWAs do not fulfil the required limits of almost all the morphological characteristics. The CWAs are generally covered with porous mortar that effects their specific gravity and enhances their angularity, water absorption and crushing values. Lack of these characteristics may hinder the reusability of the CWAs as the construction material.The Los Angeles abrasion was also determined for the aggregates and it was observed that the CWAs do not comply with the IS: 2386 Part 5 limits. Therefore, the CWAs have to be mixed with the hornfels in order to achieve required characteristics. The amount, of the CWAs which could be used to replace the hornfels, was determined by estimating the Los Angeles abrasion of the mixture of the CWAs and the hornfels, as shown in Figure2. [22-23]

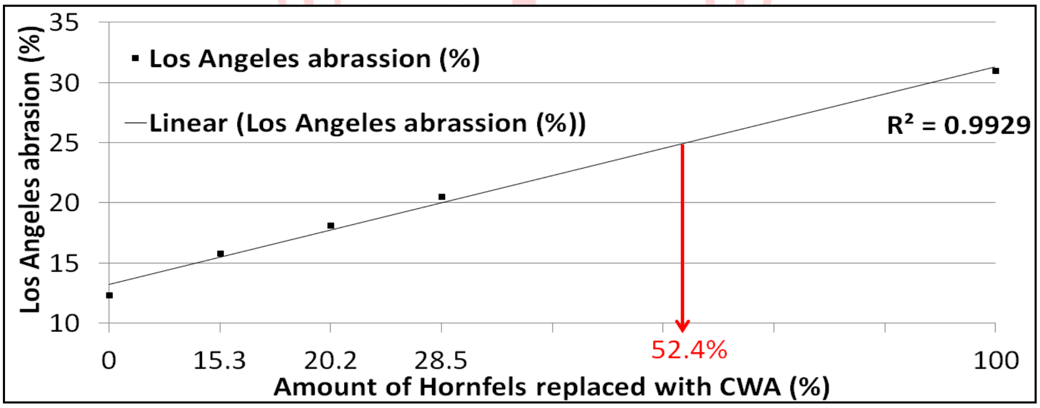

Fig. 2 Estimating the maximum replacement of the hornfels with the CWAs

From Figure 2, it can be inferred that maximum 52.4% replacement of hornfels with the CWAs could be done, so as to comply with the IS: 2386 Part 5standard limits. However, it is evident that high concentration of the CWAs may lead to high consumption of bitumen because of the absorptive nature of the CWAs (Pasadin and Perez 2013). Therefore, in present investigations, maximum 40% of the hornfels were replaced with the CWAs.

2.1.2 Other constituents

In present study, aggregates passing through the 2.36 mm sieve and retained on the 75-micron sieve were used as fine aggregates. The fine aggregates used in the study were clean, hard, durable, dry and free from dust, soft or friable matter, organic or other deleterious matter. The residual material left after separation of fine aggregates was used as filler. Laboratory tests were performed on the fine aggregates and the filler. The results of this analysis are described in Table 2.

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Table2. Laboratory test results on fine aggregates and filler (stone dust)

Materials	Test	Test Value	Requirements (MoRTH_5th_Revision)	Method of Test
Fine aggregate	Sand Equivalency	60	≥ 50	IS: 2720 (Part 37), AASHTO T176
	Specific Gravity	2.53		IS: 2386 Part III
Filler	Plasticity Index	3.5	≥ 4	IS: 2720 (Part 5)
	Specific Gravity	2.45		IS: 2386 Part III

From Table 2, it can be seen that the fine aggregate had a sand equivalency value of not less than 50 and thus, it satisfies the requirement of IS: 2720 (Part 37) or AASHTO T176. The filler used, in present study, was free from organic impurities and had a plasticity index not greater than 4, when tested according to the requirement of IS: 2720 (Part 5) (IS: 2770 (PART XXXVII) - 1976).

Bitumen of VG30 grade was used as a binder in present investigation. A laboratory analysis was done in order to evaluate the suitability of VG30 as binder. The brief descriptions of the laboratory tests conducted on VG30 and their findings are shown in Table 3.

Table3. Properties of bitumen (VG-30)

Property	Test Method	Test Results	Requirements as per IS 73:2013 for VG 30
Penetration 25°C ,100 g, 5 s, 0.1mm	IS 1203-1978	51	Min 45
Softening point (R & B), °C	IS 1205-1978	47.6	Min 47
Ductility Test, 25°C, cm	IS 1208-1978	102.1	Min 75

From Table 3, it is evident that bitumen of VG30 grade fulfills all the requirements to be used as binder, as per IS73:2013. In present investigation, 4%, 5% and 6% of the VG30 was used as binder in constructing samples of WC in the laboratory. Further, to treat the surface of the CWAs before the mixing process, a bitumen emulsion of type VG10, having bitumen content of 61%, was used. As per the affinity tests performed, before preparing the specimens, it was observed that 5% of the VG10, when used as emulsion, may show most favorable bond results. Therefore, 5% of the VG10 was used as emulsion for treating the CWAs which may also vary the final proportion of the bitumen in the specimen.

2.2 Laboratory testing

2.2.1 Preparing the specimen for optimization process

Optimization of the process, involving the use of the CWAs as aggregates in generation of WC, was performed by assessing the impacts of process parameters on response parameters. The process parameters chosen in this study were, proportion of the CWAs (treated and un-treated), temperature (considered while estimating the stiffness) and the bitumen-binder (VG30) content in the specimen. Three levels of the process parameters viz., low, medium and high, were decided, as described in Table 4.

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Table4. Three levels of the operating parameters used during statistical analysis

S. No.	Process Parameters	Symbolic representation	Units	Coded Values		
				-1 (Low)	0 (Medium)	+1 (High)
1	Proportion of Treated CWAs	X_1	%	10	25	40
2	Bitumen (VG 30) content	X_2	%	4	5	6
3	Temperature	X_3	°C	0	10	20
4	Proportion of Untreated CWAs	X_4	%	10	25	40

As mentioned in Table 4, the three levels of $X_{1 \text{ to } 4}$ were decided on the basis of findings of the previous scientific literature and available standards (Pasadin and Perez 2013). Specimen of WC were prepared by mixing the raw materials viz., binder, filler, fine aggregates, treated and untreated CWAs in required proportions. The CWAs were replaced with the coarse fraction of the mix as it is easier to perform this task manually. Before initiating the mixing process for WC, it was ensured that breaking of emulsion has begun. Cylindrical shaped specimen of 105 mm in diameter and 65 mm in height were prepared in the laboratory. These specimens were further tested for several tests such as, volumetric characteristics such as, VMA, VA, VFB, MS, FV and TSR, and stiffness. These tests are mentioned in this manuscript as response parameters. Various laboratory experiments were performed to analyse the response parameters.

2.2.2 Water resistance

Water resistance, as a proxy of moisture damage, was evaluated in terms of stripping potential of the specimen. For estimating the stripping potential TSR has been calculated, which is based on estimating the loss of indirect tensile strength of the WC specimen after getting in contact with moisture. Ten cylindrical Marshall specimen were prepared which were divided equally into two types i.e., dry and wet. Dry specimen was kept undisturbed at room temperature for three consecutive days before final analysis. However, wet specimen was saturated with water and kept in water bath at 40°C for next three consecutive days. After three days, both the types of the specimen were left undisturbed for 2h at 15°C after which tensile strength of all the specimen was evaluated following the Eq. (1).

$$TSR = (ITS_w / ITS_D) \times 100 \qquad (1)$$

Where, TSR depicts the tensile strength ratio (%); ITS_w and ITS_D show the tensile strength of the wet and dry specimen. For TSR of the WC specimen ≥ 80% is considered to be appropriate, as per specification of ASTM D 4867.

2.2.3 Stiffness test

Influence of the pre-treated CWAs on stiffness, of the specimen, was evaluated with respect to the temperature. In this regard, indirect tensile stiffness modulus test was performed on the specimen, Marshall Stability Testing Machine. As per this test, cylindrical Marshall Specimen had to go through ten conditioning have sine pulses followed by have sine test pulses. The latter were applied on the vertical diameter of the specimen. The load on the specimen was extended till 0.005% of the horizontal strain is produced. The findings of this analysis were further used to calculate resilient modulus (RM) of the specimen at different temperatures i.e., 0, 10 and 20, following the Eq. (2).

$$M_R = \frac{F \times (v + 0.27)}{z \times h} \qquad (2)$$

Where, M_R depicts the resilient modulus; *F* shows the number of repetitions of the load; *z* is the horizontal recoverable deformation (mm); *h* is the specimen thickness; *v*represents the Poisson's ration. As supported by the scientific literature, the value of *v* was assumed to be 0.35. It is also to be noted that MORTH 2000 does not have provisions for specifying the M_R. Hence, to compare the findings, similar analysis was also done on the specimen prepared using untreated CWAs also, mentioned as *controlled specimen* in this manuscript.

2.2.4 Statistical analysis

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Instead of using a time consuming and labor demanding one variable at a time (OVAT) approach a multivariate statistical approach was used to generate a relation between process parameters and response parameters. TheCCD and BBD approaches, in combination with RSM, were used to design the experiments and generate models based on either linear or quadratic relationship between the process parameters and response parameters. The relation developed between the response and process parameters using this approach can be described using Eq. (3).

$$Y = c_o + c_1X_{1(4)} + c_2X_2 + c_3X_3 + c_{12}X_{1(4)}X_2 + c_{13}X_1X_3 + c_{23}X_2X_3 + c_{11}X_1^2 + c_{22}X_2^2 + c_{33}X_3^2 \quad (3)$$

Where, Y = response parameter(s); X_1 to X_4 = process parameters and c_i= response function coefficients which were determined using Stat–Ease Design Expert (version 8.0.7.1) regression software. This software was further used to evaluate the accuracy of the generated models using analysis of variance (ANOVA). The various parameters calculated for the adequacy check were correlation regression coefficients, adjusted regression coefficients and goodness of fit. After all the statistical analysis, 3D plots of the results were also generated using RSM. Using these plots the optimum conditions were evaluated.

3. RESULTS AND DISCUSSION

3.1 Statistical evaluation

Based on the experimental results, quadratic and linear models were generated which depicted the relation between the response and process parameters. These quadratic and linear models are described in Eq. (4) through Eq. (11).

$$Y_1 = 23.74 + 0.02X_1 - 4X_2 - 0.01X_1X_2 + 4.3X_2^2 \quad (4)$$

$$Y_2 = 4.18 + 0.05X_1 - 0.25X_2 \quad (5)$$

$$Y_3 = 64.78 + 0.03X_1 + 2.55X_2 \quad (6)$$

$$Y_4 = 4.67 + 0.1X_1 + 3X_2 \quad (7)$$

$$Y_5 = 1.49 + 0.01X_1 + 0.16X_2 \quad (8)$$

$$Y_6 = 78.86 - 0.08X_1 + 2.39X_2 \quad (9)$$

$$Y_7 = 43086 - 193.84X_4 - 7897.75X_2 - 910.08X_3 + 18.35X_1X_2 + 2.54X_1X_3 - 71.97X_2X_3 + 0.75X_1^2 + 789.87X_2^2 + 18.97X_3^2 \quad (10)$$

$$Y_8 = 37661 - 443.3X_1 - 759.12X_2 - 855.27X_3 + 51.8X_1X_2 + 3.09X_1X_3 - 39.62X_2X_3 + 2.39X_1^2 + 404.87X_2^2 + 7.4X_3^2 \quad (11)$$

Where, $Y_1$to Y_8 indicate the response parameters i.e., VMA, VA, VFB, MS, FV, TSR, RM (of treated CWAs) and RM (of untreated CWAs), respectively. Among these response parameters, Y_1 to Y_6 depict the volumetric characteristics of the specimen and Y_7 to Y_8 represents the stiffness of the specimen. Further, the results, of the experiments conducted in the laboratory and their comparison with the predicted results, depicted using the models, and is described in Table 5 and Table 6. [19,23-25]

Table5. Comparison of experimental and predicted responses for volumetric properties & water resistance

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Process parameters			Experimental Responses						Predicted Responses					
	CAWs	BC(VG30)	VMA	VA	VFB	MS	FV	TSR	VMA	VA	VFB	MS	FV	TSR
S. No.	%	%	%	%	%	kN	mm	%	%	%	%	kN	mm	%
	X1	X2	Y_1	Y2	Y3	Y4	Y5	Y6	Y_1	Y2	Y3	Y4	Y5	Y6
1	40	6	15.58	4.1	83	31	2.9	92.31	15.40	4.62	**81.44**	26.75	2.78	89.65
2	25	3.58	14.78	3.9	76	16	1.9	80.62	15.22	4.49	74.76	17.96	2.27	85.19
3	25	6.41	15.83	3.1	77	21	2.6	89.16	15.37	3.78	**81.98**	26.47	2.73	**91.96**
4	40	4	16.38	4.8	74	21	2.7	88	15.58	**5.13**	76.34	20.73	2.46	84.87
5	25	5	14.43	4.7	80	24	2.6	90	14.43	4.14	**78.38**	22.23	2.50	88.59
6	10	4	14.32	4.3	75	20	2.2	89	**14.30**	3.40	77.87	17.71	2.22	89.92
7	25	5	14.43	4.7	80	24	2.6	90	14.43	4.14	**78.38**	22.23	2.50	88.59
8	46.21	5	14.77	4.9	77	19	2.4	81.83	15.46	5.18	**79.10**	24.36	2.67	86.71
9	25	5	14.43	4.7	80	24	2.6	90	14.43	4.14	**78.38**	22.23	2.50	88.59
10	25	5	14.43	4.7	80	24	2.6	90	14.43	4.14	**78.38**	22.23	2.50	88.59
11	3.78	5	15.11	1.1	72	14	2.5	89.06	14.38	**3.09**	77.66	20.09	2.33	**90.48**
12	25	5	14.43	4.7	80	24	2.6	90	14.43	4.14	**78.38**	22.23	2.50	88.59
13	10	6	14.11	4.1	85	27	2.3	91.75	14.93	3.15	**80.42**	23.73	2.54	**92.32**

Table6. Comparison of experimental and predicted responses for stiffness

Process parameters					Experimental Responses		Predicted Responses	
	TREATED CAWs	BC (VG30)	TEMP	UNTREATED CAWs	RESILIENT MODULUS (TREATED)	RESILIENT MODULUS (UNTREATED)	RESILIENT MODULUS (TREATED)	RESILIENT MODULUS (UNTREATED)
S.No.	%	%	°C	%	MPa	MPa	MPa	MPa
	X1	X2	X3	X4	Y7	Y8	Y7	Y8
1	25	5	10	25	11100	11855	11100	11855
2	25	6	20	25	5055	4806	4539.75	4512.5
3	10	5	20	10	5290	4470	5099	4895.88
4	25	6	0	25	23370	21171	22514.8	21864.8
5	25	4	0	25	21080	20402	21595.5	20695.5
6	25	5	10	25	11100	11855	11100	11855
7	40	5	20	40	**4850**	**4251**	**4701**	**4812.37**
8	10	6	10	10	11400	12848	12106	12715.6
9	10	4	10	10	13841	13625	13176.7	13892.9
10	25	5	10	25	11100	11855	11100	11855
11	25	4	20	25	5644	5622	6499	4928.25
12	40	6	10	40	10830	13526	11494	13258
13	40	5	0	40	20281	20870	20472	20444
14	10	5	0	10	22250	22945	22399	22383.6
15	40	4	10	40	12170	11195	11463.8	11327.4
16	25	5	10	25	11100	11855	11100	11855
17	25	5	10	25	11100	11855	11100	11855

From Table 5 and Table 6, it is evident that the responses predicted using the models were similar to the experimental responses. The regression coefficient (R^2) for each response parameter i.e., VMA, VA, VFB, MS, FV, TSR, RM (of treated CWAs) and RM (of untreated CWAs), is 0.81, 0.73, 0.81, 0.77, 0.80, 0.75, 0.94 and 0.96, respectively. Hence, to understand the adequacy of the results, derived from models, further correlation analysis using ANOVA was done and its findings are shown in Table 7.

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Table7. Outcomes of ANOVA depicting significance of different mode

Source	P-Value							
	VMA	VA	VFB	MS	FV	TSR	RM(T)	RM(UN-T)
Model	0.0014*	0.001*	0.002*	0.001*	0.003*	0.004*	<0.0001*	<0.0001*
X_1	0.03*	0.04*	0.02*	0.03*	0.01*	0.22	0.05	-
X_2	0.79	0.41	0.09	0.07	0.06	0.07	0.36	0.38
X_3	-	-	-	-	-	-	0.004*	0.001*
X_4	-	-	-	-	-	-	-	0.04*
X_1X_2	0.65	-	-	-	-	-	0.48	-
X_1X_3	-	-	-	-	-	-	0.34	-
Y_2Y_3	-	-	-	-	-	-	0.098	0.21
X_4X_2	-	-	-	-	-	-	-	0.03*
X_4X_3	-	-	-	-	-	-	-	0.15
X_1^2	0.33	-	-	-	-	-	0.65	-
X_2^2	0.11	-	-	-	-	-	0.06	0.09
X_3^2	-	-	-	-	-	-	0.001*	0.19
X_4^2	-	-	-	-	-	-	-	0.03*
Model type	Quadratic	Linear	Linear	Linear	Linear	Linear	Quadratic	Quadratic

From Table 7, it can be seen that at 95% confidence level, the p-values of the models were significant enough (i.e., ≤ 0.05) to generate reliable results. Hence, they were further used for generating the optimization process-based response surface plots, as shown in Figure 3 and Figure 4.

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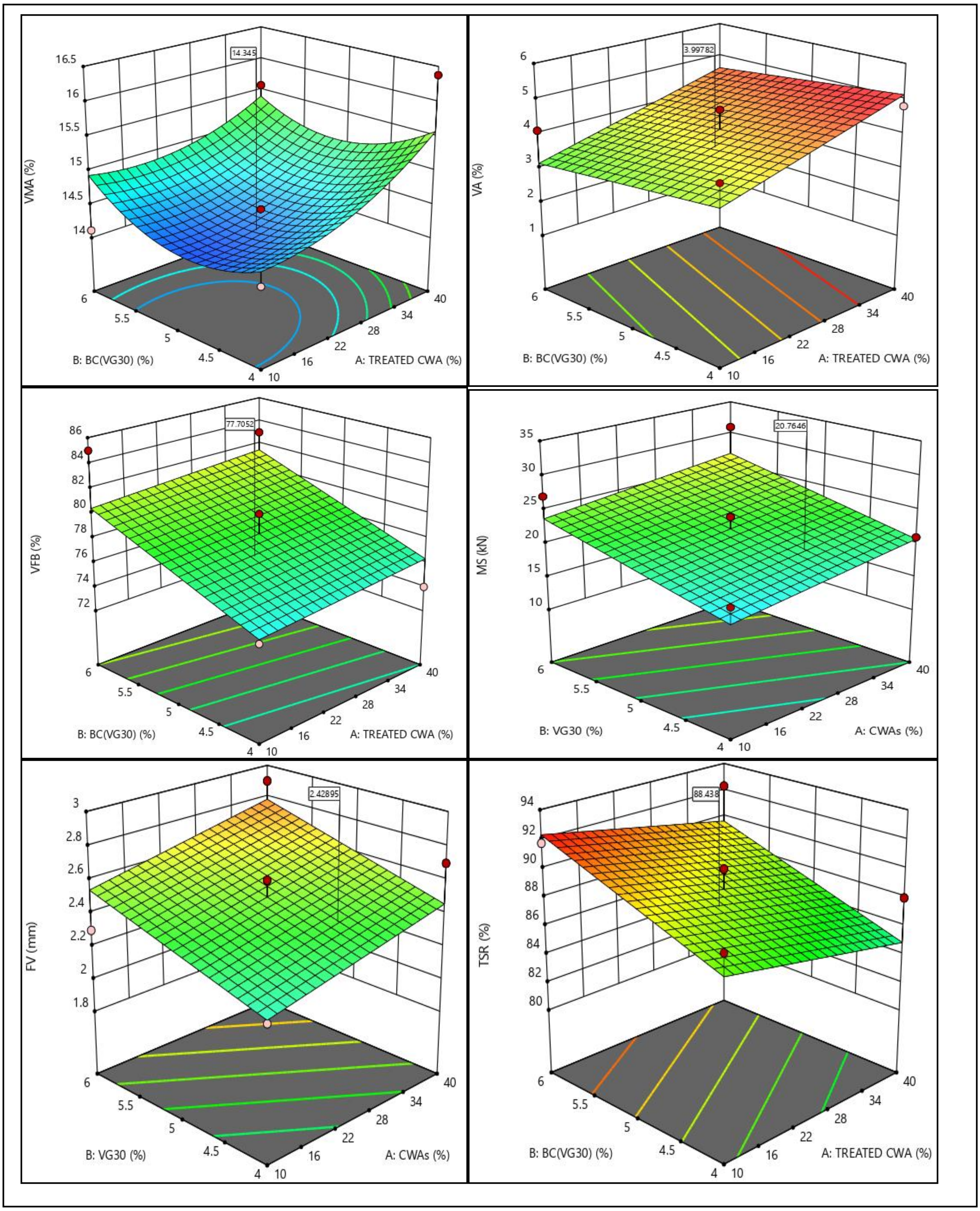

Fig. 3 Surface plots for volumetric properties and water resistance

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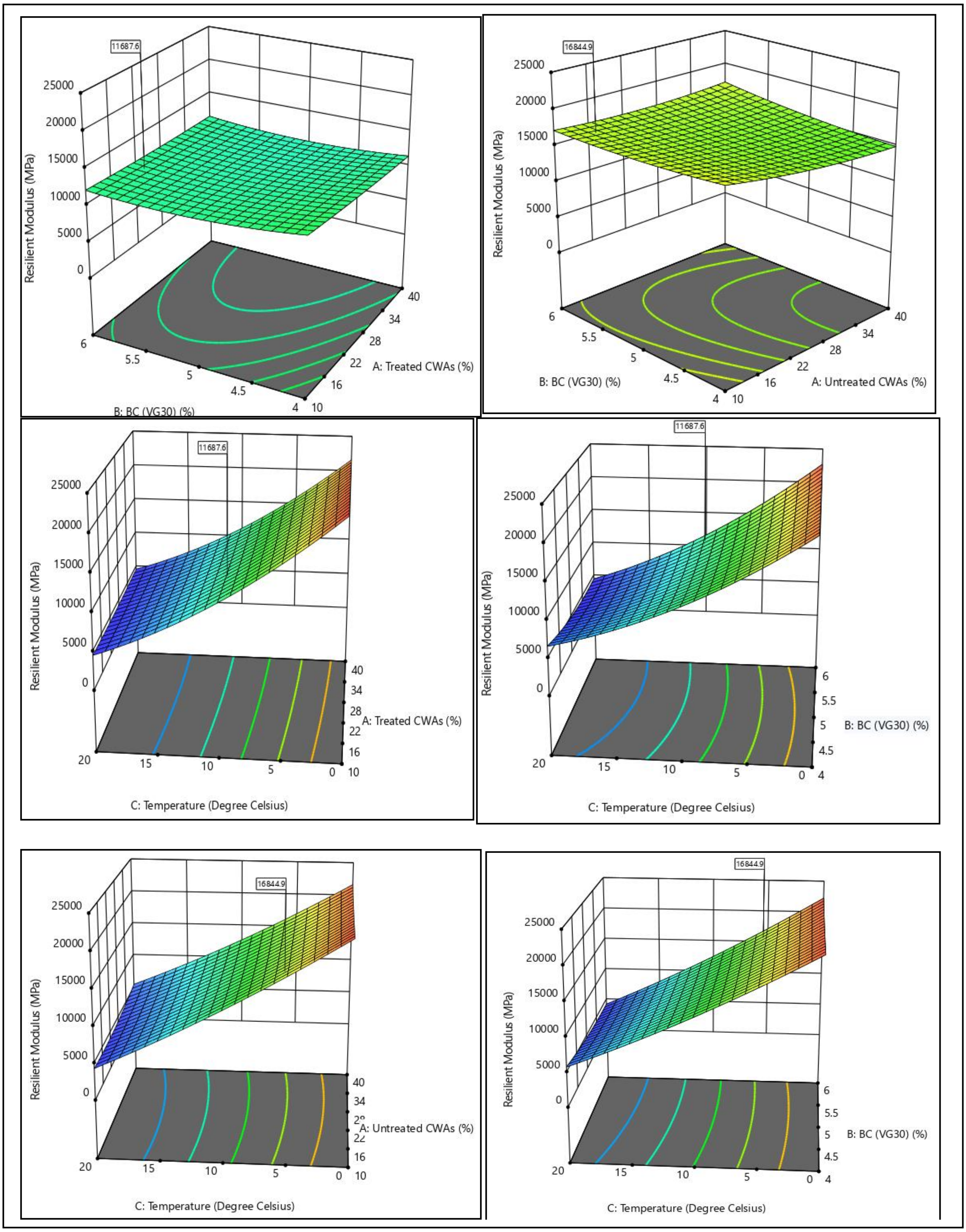

Fig. 4 Surface plots of stiffness

Volumetric properties

Changes in volumetric properties viz., VMA, VA, VFA, MS and FV, on usage of CWAs as construction material of the WC are shown i2n Figure3. The response surface plots showed that all the volumetric properties except, VMA, showed a linear relationship with the process parameters. These findings also make it evident that as per standards described in MORTH 2009 for WC, all the volumetric properties expect VFA were not severally impacted on using CWAs. Among the other volumetric properties, VMA of some of the specimen also could not comply with the requirements when the percentage of CWAs and BC (VG30) were 10% and 4%. Moreover, specimen having 40% and 4%; 3.78% and 5%, of the CWAs and the BC (VG30) were

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observed unsuitable for construction of WC as their values of VA were compromised. However, it was encouraging to report that for the entire specimen, designed in the laboratory, MS and FV were reported to fall within the requirements needed for construction of WC. Observations made using the volumetric properties also proved that low % of the CWAs, in the specimen, could significantly impact the VMA, VA and VFA. Therefore, substantial consideration should be given while choosing the amount of the CWAs to be used in construction of the WCs. Results of two-way ANOVA, as described in Table 7, also showed that proportion of the CWAs is significantly related (< 0.05) to the volumetric properties which are not in the case of the proportion of the bitumen content. Hence, it also confirms the judgement that to attain required characteristics of WC, the proportion of the CWAs should be chosen carefully.

3.3 Water resistance

Mortar attached to the CWAs is observed to increase their water absorption capacity and reduce its resistance. Hence, in this study, tensile strength ratio (TSR) of the specimen, at different proportions of the CWAs, was also analysed and its findings are shown in Figure 3.

From the Table 7 and Figure 3, it could be depicted that pre-treatment of the CWAs with bitumen has reduced its permeability as most of the specimen were reported to have TSR within the required limits. Only the specimen having CWAs and BC content of 25% and 6.41%; 3.78% and 5%; 10% and 6%, respectively, showed the TSR values > 90%. Analysis based on two-way ANOVA also showed that TSR did not have any significant relation with the proportion of the CWAs in the specimen. Hence, it can be implied that after pre-treatment of the CWAs with the bitumen emulsion, ameliorated the characteristics of the CWAs and made them act similar to the natural aggregates. [21-25]

3.4 Stiffness

Resilient modulus (RM) was used as an epoxy to define stiffness of the specimen prepared using the CWAs. Comparison of the specimens' RM consisting of the treated and untreated CWAs was done. It was revealed that average value of the RM for untreated and treated specimen was greater than 5000 MPa which was generally observed RM value for WC. Hence, it could be implied that the specimen prepared using the treated CWAs behave similar to natural mixtures and do not reduce their RM. On the contrary, it was observed that replacing the untreated CWAs with treated CWAs decrease the stiffness of the specimen. Hence, decrease in stiffness of the specimen with increased content of bitumen, can also be inferred.

Further, to assess the impacts of weather on the specimen, changes in their stiffness with respect to the temperature of the surroundings were also evaluated. The response surface plots, as shown in Figure 4, depict that there was a quadratic relation between the temperature and stiffness of the specimen. It could be seen that with increase in temperature the stiffness of the specimen (both treated and untreated) was observed to decrease. At lower temperature both types of the specimen were observed to have higher stiffness. However, on neglecting the impacts of temperature, it was revealed that untreated specimen was stiffer than the treated ones. Similarly, two-way ANOVA also depicted that more significant relation between the temperature and RM of the specimen, followed by the proportion of the CWAs.

3.5 Optimization

The statistical models and response surface plots generated using Design Expert software were further used to evaluate the optimal conditions for the process and response parameters. The values of the various process and response parameters observed during the optimal conditions are described in Table 8.

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Table 8. Optimum conditions for response parameters

Response parameters	Optimized conditions	Process parameters		
		Proportion of treated CWAs	Bitumen (VG 30) content	Temperature
VMA	14.34%	21.02	4.79	-
VA	3.99%	21.02	4.79	-
VFB	77.71%	21.02	4.79	-
MS	20.76 kN	21.02	4.79	-
FV	2.42 mm	21.02	4.79	-
TSR	88.43%	21.02	4.79	-
RM(T)	11687.6 MPa	21.02	4.79	9.9

From Table 8, it can be implied that under optimized conditions, i.e., pre-treated CWAs = 21.02%; bitumen (VG30) = 4.79%; temperature = 9.9°C, values of all the response parameters were within the required limits, as set by MORTH (2000). Hence, the experiments designed in this investigation using the Design Expert software, were found to be suitable in deciding the optimal conditions of the process parameters under which suitable construction material for WC could be prepared.

4. CONCLUSIONS

The current analysis's findings showed that CWAs salvaged from a road maintenance site in a mountainous area of India could significantly substitute natural aggregates when building WCs. Pre-treatment of the CWAs with the bitumen emulsion has proven beneficial in improving their characteristics and making them suitable for construction purposes. Various characteristics such as, VMA, VA, VFA, MS, FV, TSR and RM of the laboratory specimen were found similar to the natural aggregates. Further, optimization process performed using RSM, showed that under optimized conditions, i.e., pre-treated CWAs = 21.02%; Bitumen (VG30) = 4.79%; Temperature = 9.9°C, values of all the response parameters were within the required limits, as set by MORTH (2000). Therefore, it was determined that laboratory specimens created in accordance with experiments performed utilizing multivariate techniques, namely CCD and BBD, were suitable for use in the creation of WC. Therefore, it is advised that the CWAs not be dumped and that their repurposing for building be promoted. The numerous initiatives being undertaken around the world to fulfill the deadlines for accomplishing different sustainable development goals could be aided in this way.

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