Optimization and performance evaluation of crushed stone waste as an alternative material in flexible pavement base layers

S. Muthu Lakshmi*, *T. Eswary* Devi, *S. Surya Narayana* Murthy, *G.* Swetha, and *V.* Yogesh
Department of Civil Engineering, Rajalakshmi Engineering College, Chennai, Tamil Nadu, India

Abstract. Exhaustion of conventional non-renewable natural assets like coarse and fine aggregates used in the construction sector is the major issue currently faced by the construction industry. To overcome this problem of depletion of aggregates, an initiative has been taken in the current work to replace Gravel Chips (GC) of size 10mm to 4.75mm and M Sand (MS) with crushed stone sludge waste (CSSW) up to a percentage of 50% as part of base and sub-base layers in flexible pavement structure. CSSW is a dust waste from stone crusher units produced during the crushing of stones, rocks etc., which when utilized as replacement to GC and MS will cut down on amount of waste being disposed in surrounding environment, consequently reducing environmental pollution. Expenses responsible for discarding the waste can be reduced, material costs related to purchasing of coarse and fine aggregates for flexible pavement base and sub-base layers can be minimized, resulting in a construction that is both cost-efficient and eco-friendly. Peak MDD of 2.14 gm/cc and 2.08 gm/cc was attained for GC replaced with 40% CSSW and for MS replaced with 30% CSSW respectively due to filling of the voids within GC and MS with finer CSSW. Optimum replacement of GC with CSSW was 40% - 50% whereas, that of MS was 30% - 40% based on maximum CBR strength achieved by the mix. A reduction in pavement thickness by approximately 34.2% and 51% was achieved for GC and MS replaced with 40% CSSW respectively.

1 Introduction

Decline in natural reserve availability and surge in cost of existing resources highlight the need to explore substitute materials [1]. Boom in construction activities all over the world has led to depletion of conventional natural resources such as coarse and fine aggregates leading to alternate manufactured materials such as crushed stone aggregates and M Sand (MS). The surge in construction activities has significantly raised the consumption of crushed stone aggregates in concrete applications, resulting in a growing demand for these materials [2-4]. During the manufacturing of coarse and fine aggregates by crushing large stones and rocks in crushers, lot of fine dust particles of size less than 75 microns is produced which is separated either by blowing air or by washing with water.

* Corresponding author: muthulakshmi.s@rajalakshmi.edu.in

Fine dust particles collected by blowing air are called crushed stone dust waste. Dust particles that are separated by washing the manufactured aggregates are retained in ponds and left to settle at bottom as sludge waste which is then dumped in surrounding landfills and left to dry. This sludge waste in dried state is called crushed stone sludge waste (CSSW) which has been utilized in the current experimental investigation for replacing Gravel Chips (GC) and MS used in base and sub-base layers in the construction of flexible pavement. GC used in present work is of size 10 mm to 4.75 mm and MS is of size less than 4.75 mm which were manufactured by crushing granite rocks.

Number of research works have been performed to utilize wastes generated from industries, power plants, construction sector as a geomaterial within soil aimed at enhancing soil's engineering characteristics. Crusher dust—such as stone dust, quarry dust, M-sand dust, gravel dust, marble dust, and granite dust - by-product generated in huge volumes during aggregate crushing processes. Typically, around 15% to 20% of the total output from each crusher unit consists of this dust. Mismanagement in discarding these materials poses significant environmental and public health concerns due to excessive accumulation and airborne particles [1-3, 5-11]. The pace of industrial growth has caused a shortage of land for disposing of industrial wastes and has simultaneously driven up the demand for construction activities. The accumulation and environmentally safe management of this waste materials have become significant environmental challenge [2]. As per [12], grain size distribution of quarry dust powder was similar to that of sand, with particles typically measuring less than 90 microns. The physical characteristics, chemical makeup, and mineral content of quarry dust differ based on the type of aggregate and the producer, yet they remain fairly uniform within a specific quarry site [13]. Incorporating crusher dust wastes into soil—whether as an additive or as a partial or total replacement for local soils in geotechnical projects—cuts down disposal volumes, promotes waste management and resource conservation, and also fosters more economical, sustainable construction [4, 6]. Crusher dust can be suitably employed as a material for embankments, backfill in the lower layers of sub-base courses, and as a capping layer over very weak subgrade. Its application in such filling works offers cost-effective solutions and minimizes environmental impact [1, 3, 5, 14]. Crusher dust has also been successfully used as an additive in expansive soils to stabilize and improve their geotechnical characteristics [9]. Inclusion of crusher dust enhances engineering behaviour of soil, including increased density, reduced swelling and plasticity, and improved strength parameters such as shear strength, CBR value, and load-bearing capacity. A higher CBR value in subgrade soil mixed with crusher dust allows for a reduction in depth of the flexible layer, resulting in cost-effective construction [3, 7-9, 11]. With an increase in proportion of quarry dust in soil, its cohesion tends to decrease, while internal friction angle improved. Additionally, both Poisson's ratio and the elastic modulus show an upward trend with higher quarry dust content [11].

Baby GC, also referred to as baby chips or blue metal, are widely utilized in construction due to their specific size and characteristics. These are typically crushed stone aggregates, ranging in size from 6 mm to 20 mm. They are commonly employed in concrete mixing, roadworks, drainage installations, and landscaping projects. Among these, 6 mm and 10 mm chips are ideal for finer concrete applications, while 20 mm chips are better suited for road construction and larger concrete elements. In flexible pavement construction, underlying base layer is usually composed of crushed stone, gravel, or sand, and serves to transfer loads from the upper pavement layers to the underlying subgrade whereas the base course, provides essential structural strength to the pavement and is generally made from materials including asphalt, concrete, or crushed stone. In recent years, the pace of transportation infrastructure development has significantly increased. However, the shortage of road construction materials has necessitated sourcing from distant locations, raising project costs and often

falling short of local construction needs. As a result, using raw materials available at or near construction sites has become a practical, efficient, and cost-effective alternative [14-15].

2 Methodology

In the current work, CSSW has been utilized as a replacement to GC and MS in percentages of 10% to 50% by dry weight of virgin GC and virgin MS. Index properties of CSSW, MS and GC were studied in detail apart from the compaction and strength characteristics of various combinations of GC-CSSW and MS-CSSW. Based on the influence of CSSW on compaction and strength characteristics, ideal proportion of CSSW to be added to GC and MS as a replacement was identified. Flexible pavement depth was calculated based on soaked CBR value of GC-CSSW mix and MS-CSSW mix. Percentage increase or decrease in pavement thickness was then calculated compared to that of virgin GC and MS. Feasibility of utilizing GC-CSSW and MS-CSSW mix as flexible pavement base or sub-base layers and for the purpose of complete replacement of weak expansive subgrade soil in ground stabilization was studied. As future scope of work, chemical characterisation of CSSW can be carried out and implementation of GC-CSSW mix and MS-CSSW mix in pilot road projects can be included. One of the limitations of utilizing CSSW within soil would be the variability in chemical and mineralogical composition of crushed stone waste across different quarries, which needs to be addressed in future research work.

3 Experimental results

Properties of the materials used in the experimental work such as CSSW, MS and GC were evaluated in accordance with IS code procedures [IS:2720 (Part 4) – 1985; IS: 2720 (Part III/Sec 2) – 1980; IS:2720 (Part 5) – 1985; IS: 2720 (Part 8) – 1983]. The materials employed in the experimental work were categorized as per IS soil classification system based on particle gradation and plasticity behaviour [IS:1498 – 1970]. Table 1 presents the basic properties of materials used.

Table 1. Properties of CSSW, MS and GC.

Soil Tests	CSSW	MS	GC
Specific Gravity	2.69	2.35	2.94
Wet Sieve Analysis Gravel Content Sand Content Fines Content Silt Content Clay Content	 0 21.2 78.8 60.5 18.3	 0 94.6 5.4 5.1 0.3	 100 0 0 0 0
LL, PL	Non-Plastic	Non-Plastic	Non-Plastic
IS Classification	ML (Silt of Low Plasticity)	SW-SM (Well graded Sand – Silty Sand)	GP (Poorly Graded Gravel)
Bulk Density (gm/cc)	1.25	1.63	1.35
Modified Proctor Test (MPC) MDD (gm/cc) OMC (%)	 1.816 14.5	 2.06 11.1	 - -

CSSW was classified as ML, MS as SW-SM and GC as GP as the particle sizes of GC were approximately 10 mm to 4.75 mm. As CSSW was non-cohesive and non-plastic in nature, it can be used as a partial replacement to GC and MS, utilized in the construction of base and sub-base layers of flexible pavement.

3.1 Modified proctor compaction (MPC) test

MPC test was conducted [IS: 2720 (Part 8) – 1983] on GC and on MS replaced with variable quantity of CSSW as per the IS Code procedure. CSSW was incorporated at 10%, 20%, 30%, 40%, and 50% of dry weight, as a partial replacement to GC and MS. MPC test could not be conducted on Virgin GC and on GC replaced with 10% CSSW as MPC test is generally conducted on fine aggregates (sand and fine-grained soil) and not on coarse aggregates (gravels). Table 2 presents result of MPC test conducted on GC and MS replaced with varying percentages of CSSW. Figures 1 and 2 shows the MDD and OMC of GC and MS replaced with varying percentages of CSSW respectively.

Table 2. MPC test results conducted on GC and MS replaced with varying percentages of CSSW.

Specimen	OMC (%)	MDD (gm/cc)
MS	11.1	2.06
CSSW	14.5	1.816
0.8 GC + 0.2 CSSW	10.92	1.86
0.7 GC + 0.3 CSSW	9.13	2
0.6 GC + 0.4 CSSW	8.64	2.14
0.5 GC + 0.5 CSSW	8.53	2.11
0.9 MS + 0.1 CSSW	9.66	1.97
0.8 MS + 0.2 CSSW	9.2	2
0.7 MS + 0.3 CSSW	9.01	2.08
0.6 MS + 0.4 CSSW	7	2.03
0.5 MS + 0.5 CSSW	7.14	2.03

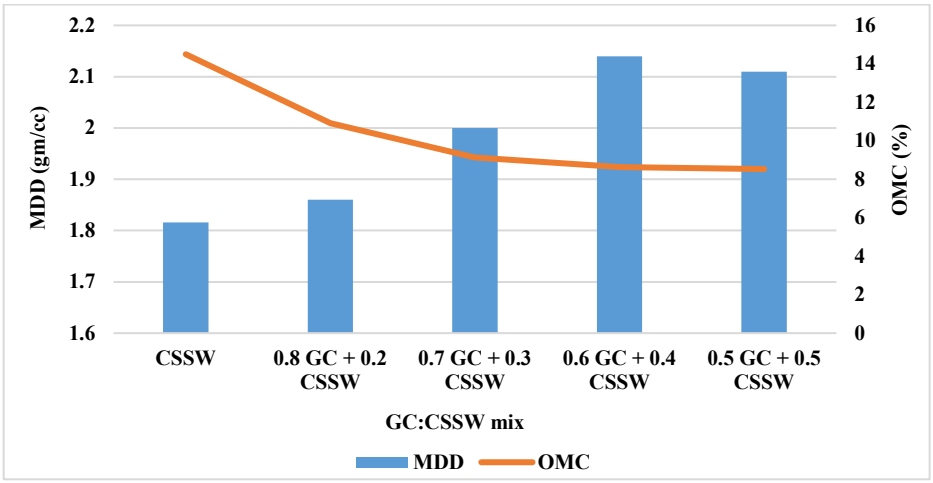

Fig. 1. MDD and OMC of GC replaced with varying proportions of CSSW.

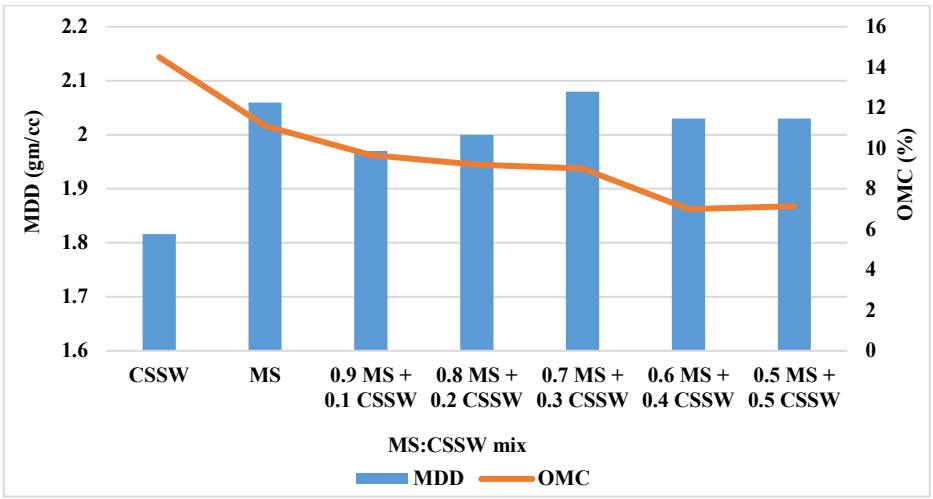

Fig. 2. MDD and OMC of MS replaced with varying proportions of CSSW.

Peak MDD of 2.14 gm/cc at OMC of 8.64% was attained for GC replaced with 40% CSSW. Peak MDD of 2.08 gm/cc at OMC of 9.01% was attained for MS replaced with 30% CSSW compared to that of 2.06 gm/cc at 11.1% attained for virgin MS. Rise in MDD can be attributed to the voids within GC and MS being filled with CSSW, thus reducing the porosity and increasing the density of the mix, hence leading to probable increase in strength of the mix.

3.2 CBR Test

Unsoaked and soaked CBR test were conducted [IS 2720 (Part 16) - 1987] on GC and on MS replaced with varying percentages of CSSW. Soil specimen was prepared in accordance with the requirements of the CBR test procedure using dynamic compaction based on MDD and OMC found from MPC test. For CBR test under soaked conditions, prepared soil specimen was immersed in water for a duration of four days. Flexible pavement depth was calculated as per soaked CBR value of the specimen assuming medium traffic and tyre pressure of 9 kg/cm^2. Table 3 and Table 4 displays CBR strength of GC and MS blended with different

proportions of CSSW respectively and also, shows the calculated depth of flexible pavement which is graphically displayed in Figure 3 and Figure 4.

Table 3. CBR strength of GC blended with different proportions of CSSW.

Specimen	Unsoaked CBR Strength (%)	Soaked CBR Strength (%)	Flexible pavement thickness (mm) as per soaked CBR strength	Reduction percentage in pavement thickness w.r.t. GC
GC	30.69	10.54	230.9	-
CSSW	14.24	10.17	236.2	-
0.9 GC + 0.1 CSSW	9.2	4.31	389.0	-
0.8 GC + 0.2 CSSW	12.38	11.83	214.3	7.2
0.7 GC + 0.3 CSSW	16.05	13.49	196.2	15.0
0.6 GC + 0.4 CSSW	20.15	19.04	151.9	34.2
0.5 GC + 0.5 CSSW	21.45	13.8	193.2	16.3

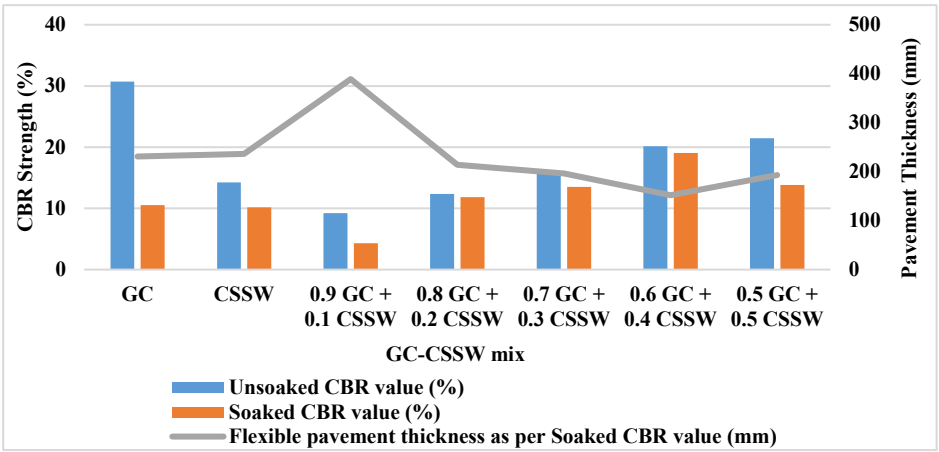

Fig. 3. CBR value and flexible pavement thickness of GC replaced with varying proportions of CSSW.

Peak unsoaked CBR strength of 21.45% was attained for GC replaced with 50% CSSW whereas maximum soaked CBR strength of 19.04% was attained for GC replaced with 40% CSSW. Thus, as per CBR strength gain, optimal substitution of GC with CSSW was found to be approximately 40% to 50%. This may be due to the fact that, with increasing quantity replacement of GC with CSSW, the voids within GC are filled with CSSW, thus increasing the density of GC-CSSW mix and hence, increasing CBR value of GC-CSSW mix. Depth of flexible pavement was found to decrease with increasing soaked CBR strength. Maximum reduction in pavement thickness by approximately 34.2% was achieved for GC replaced with 40% CSSW calculated with respect to that of virgin GC.

Table 4. CBR strength of MS blended with different proportions of CSSW.

Specimen	Unsoaked CBR Strength (%)	Soaked CBR Strength (%)	Flexible pavement thickness (mm) as per soaked CBR strength	Reduction percentage in pavement thickness w.r.t. MS
MS	32.29	15.51	177.8	-
CSSW	14.24	10.17	236.2	-
0.9 MS + 0.1 CSSW	30.69	25.79	115.1	35.2
0.8 MS + 0.2 CSSW	33.28	29.52	98.8	44.5
0.7 MS + 0.3 CSSW	44.37	32.17	88.1	50.5
0.6 MS + 0.4 CSSW	44.19	32.4	87.2	51.0
0.5 MS + 0.5 CSSW	25.79	24.68	120.4	32.3

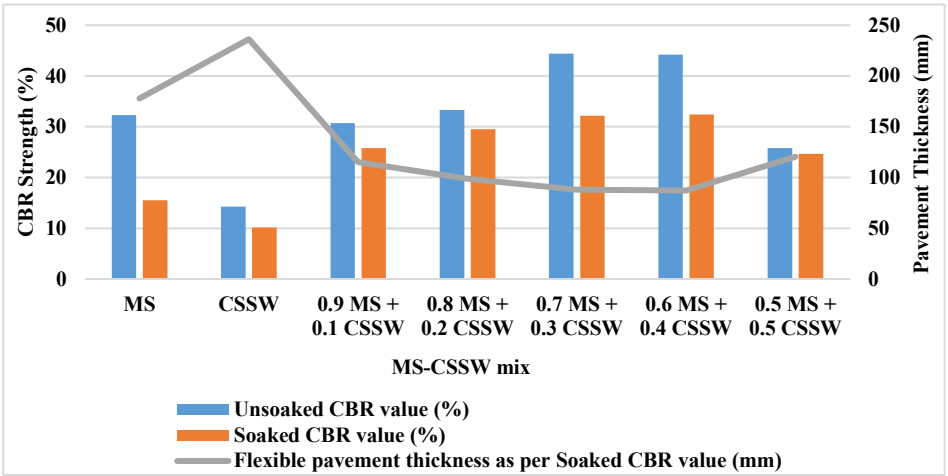

Fig. 4. CBR value and flexible pavement thickness of MS replaced with varying proportions of CSSW.

Peak unsoaked CBR strength of 44.37% was attained for MS replaced with 30% CSSW whereas peak soaked CBR value of 32.4% was reached for MS replaced with 40% CSSW. Thus, as per CBR strength gain, optimal substitution of MS with CSSW was found to be approximately 30% to 40%. This may be due to the fact that, with increasing quantity replacement of MS with CSSW, the voids within MS are filled with finer CSSW, thus increasing the density of MS-CSSW mix and hence, increasing the CBR strength of MS-CSSW mix. Voids within GC are of large size compared to that of MS, thus, more CSSW is required to fill the voids within GC to form a compact dense structure. This may also be the reason for higher CBR strength attained for MS-CSSW mix compared to that of GC-CSSW mix. Maximum percentage decrease in pavement thickness of about 51% was achieved for MS replaced with 40% CSSW calculated with respect to that of virgin MS. Thus, decrease in pavement thickness due to increased CBR strength leads to cost effective construction and

also, preserves the conventional raw materials used in the construction of flexible pavement for future generations.

4 Conclusion

Peak MDD of 2.14 gm/cc and 2.08 gm/cc was attained for GC replaced with 40% CSSW and for MS replaced with 30% CSSW respectively. MDD increased due to the filling of the voids within GC and MS with finer CSSW, thus leading to reduced porosity and increased density of mix, which in turn led to improvement in soil strength and engineering properties. Peak unsoaked CBR of 21.45% was observed for GC replaced with 50% CSSW whereas peak soaked CBR of 19.04% was reached for GC replaced with 40% CSSW. Thus, as per CBR strength gain, optimal substitution of GC with CSSW was found to be in the range of 40% to 50%. Peak unsoaked CBR of 44.37% was reached for MS replaced with 30% CSSW whereas peak soaked CBR of 32.4% was reached for MS replaced with 40% CSSW. Thus, as per CBR strength gain, ideal substitution of MS with CSSW was found to be approximately 30% to 40%. An approximate maximum reduction in pavement thickness of 34.2% and 51% was achieved, evaluated in accordance with soaked CBR strength of mix, for GC and MS replaced with 40% CSSW respectively. CSSW is non-cohesive and non-plastic in nature and thus, it can be used as a partial replacement to GC and MS in construction pertaining to base and sub-base layers in flexible pavement. GC-CSSW and MS-CSSW mix can also be utilized for complete replacement of weak expansive subgrade soil, thus reducing the cost of ground stabilization in weak soil. Utilizing wastes from stone crushers available in huge quantities at cheaper rates, with GC and MS as a partial replacement, results in an economical, eco-friendly and sustainable construction.

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