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Application of Class C Fly Ash and Quarry Dust Mix for Utilization as Subbase Material in Flexible Pavement

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ABSTRACT

Depleting good quality natural aggregates and soils call for the need of use of industrial by-products and waste materials in road construction. Use of wastes and by-products in road construction consume large quantities and resolve issue of their safe disposal. Class C fly ash is the by-product from thermal power plants while quarry dust is waste left behind during quarrying processes. This study investigated the application of class C fly ash and quarry dust mix for utilization in subbase layer of flexible pavement. The class C fly ash and quarry dust mixed were studied with the help of unconfined compressive strength test, repeated load triaxial test, durability test and microstructural analysis. The mixture of 90% fly ash plus 10% quarry dust was found to be suitable with respect to strength and durability criteria to be used as subbase material in flexible pavement. Owing to the formation of cementitious phases during pozzolanic reaction, proposed mix demonstrated significantly higher resilient modulus than conventional granular subbase material. The service life ratio for pavement with proposed mix is 1.2 and 1.26 in fatigue and rutting respectively compared to conventional pavement. The use of quarry dust and fly ash in large quantities in flexible pavement is an economical as well as sustainable solution for road construction.

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1. INTRODUCTION

Rapid infrastructure development is crucial economic driver and responsible for overall growth of nation. Construction of roads network is one of the prime components of infrastructure sector. The Bharatmala project designed by Government of India aims at vigorous construction of roads, highways, and expressways. The construction of road pavements demands good quality natural aggregates in large quantities. Nowadays, it is difficult to obtain good quality aggregates for road construction due to depleting natural resources [1]. Hence, it is utmost important to use industrial wastes and by products for road construction to minimize requirement of natural resources. Industrial wastes and by- products such as fly ash [2, 3], steel slag [4], copper slag [5], silica fume, ground granulated blast furnace slag (GGBS) [6, 7] are widely used in construction. By-products such as Fly ash, silica fume, GGBS and rice husk ash are also used as supplementary cementitious materials in construction materials [8,9,10]. Apart from industrial waste, recycled aggregates along with polymers [11] as well as recycled asphalt pavement materials [12] are identified as eco-friendly and feasible materials for replacing conventional natural aggregates in road construction.

Fly ash is one of the industrial by-products which possess pozzolanic properties due to the presence of calcium oxide, silica and alumina which can enhance the properties of soils when used for stabilization purpose [13]. Based on oxide content, fly ashes are classified as classes ‘C’ and ‘F’[14].

Class C fly ashes are self-cementitious and do not require activator for initiation of hydration process. Many researchers have contributed towards utilization of fly ash along with natural aggregates and soils as road embankment, base, subbase, and subgrade materials.

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Class C fly ashes are previously studies for used in embankments, subgrade, base, and subbase of flexible pavement as additive for strength improvement and reduction in expansive properties of soils [15,16]. Class C fly ash was used along with copper slag as pavement base material and the suitability of mix was demonstrated through comparative study of full-scale pavement sections made using conventional material as well as proposed mix in field [17]. The dredged sediments were stabilized using class C fly ash and cement for pavement application. It was found that the strength, resilient modulus and CBR value of sediments were improved in order that the mix was suitable as pavement material [12]. Utilization of reclaimed asphalt pavement material along with class C fly ash was investigated for base application in flexible pavement and was found to be suitable in accordance with the design standards [18]. Use of class C fly ash for stabilization and reuse of reclaimed asphalt pavement materials and recycled concrete aggregates is investigated through freezing and thawing for highway base construction [19]. Addition of class C fly ash to conventional materials used in base and subbase layers cause significant strength improvement and consequently reduction in layer thicknesses. Hence, using class C fly ash in pavement in bulk quantities is economical and sustainable [2].

The quarry dust is coarse material that is generated as a by-product of the crushing process is a material that can be utilized as aggregates, particularly as fine aggregates. The rock is broken down into fragments of varying sizes before it is used in the quarrying process. Quarry dust is a type of waste that is produced as a byproduct of this operation and is referred to as the dust. Therefore, it becomes a material that is of no use and contributes to the pollution of the air. As a result, quarry dust if used in construction projects; can potentially bring about a reduction in the cost of construction, as well as the saving of construction material and the optimal utilization of natural resources. In recent years, many studies are conducted based on utilization of quarry dust for construction purpose [20]. The ferrochrome slag was used along with quarry dust as alternative to conventionally used aggregates in pavement, it was found that the ferrochrome slag and quarry dust mix can be effectively used base and subbase of flexible pavement [21]. Stabilization of soft subgrade was attempted using quarry dust and it was observed that addition of quarry dust to soft soil yielded in higher CBR compared to untreated soil [22]. Quarry dust used for treating expansive clay for road foundation was found to inhibit the swelling properties of clay and an economical for natural soil stabilization for road construction [23].

Class C fly ash is the by-product from thermal power plants and quarry dust is waste produces in aggregate crushing plants. Conventionally used natural aggregates and soil for subbase construction in road is limited and non-renewable resource. It is the need of the hour to use the waste materials in pavement construction on large scale to cut down the use of depleting natural resources. IRC 37 [24] permits provision of cemented subbase in flexible pavement along with crack relief layer. This study aims to assess the feasibility of use of class C fly ash along with quarry dust as subbase material in flexible pavement.

2. METHODOLOGY

2. 1. Materials As per ASTM D618 [14], fly ash used in this study classifies as class ‘C’ fly ash. The chemical composition of fly ash is stated in Table 1. The quarry dust used in this study was collected from local aggregate crushing plant in Surat, Gujarat. The quarry dust had particle passing through 1.18mm sieve.

2. 2. Experimental Program For trial mixes, the fly ash was replaced with different percentage of quarry dust equal to 10%, 20%, 40% and 60%. The modified proctor test as per IS 2720-Part 8 [25] was performed on all trial mixed to find out the maximum dry density (MDD) and optimum moisture content (OMC). The mix designations along with description are given in Table 2. Further, cylindrical samples measuring 100mm height and 50mm diameter were cast using the MDD and OMC value for each mix. Such cylindrical specimens were used to perform the unconfined compressive strength (UCS) test on specimens in accordance with IS 2720-Part 10 [26]. Similar cylindrical samples were cast to obtain

TABLE1. Chemical composition of fly ash used in the study

Parameter	Content (%)
SiO_2	36.8
Al_2O_3	3.82
Fe_2O_3	14.78
CaO	25.12
MgO	0.895
Na_2O	0.55
SO_3	10.03

TABLE 2. Description of mixes used in the study

Mix description	Designation
90% fly ash + 10% quarry dust	C10QD
80% fly ash + 20% quarry dust	C20QD
60% fly ash + 40% quarry dust	C40QD
40% fly ash + 60% quarry dust	C60QD

weight loss upon subjecting to alternate wetting and drying as per ASTM D559 [27]. Based on results of UCS and weight loss, the mix qualifying IRC criteria was chosen for obtaining the resilient modulus (MR) values as per AASHTO T307 [28], which is key parameter for designing the flexible pavement. MR value indicates the response of pavement materials to actual loads imposed on layers due to movement of traffic [29]. The microstructural development of phases within the mix was analyzed using the X-ray Diffraction (XRD) and Scanning electron microscopy (SEM) methods.

3. RESULTS AND DISCUSSION

3. 1. Standard Proctor Test Figure 1 shows that as the percentage addition of quarry dust in fly ash increases, the MDD of mix increases. This is due to addition of quarry dust particles which have higher specific gravity than fly ash particles. It can be observed from Figure 1 that the OMC value go on decreasing with the percentage substitution of fly ash with quarry dust. This is because as soon as water is added to class C fly ash, the pozzolanic reaction initiates. For the pozzolanic reaction to take place, fly ash consumes water. When quarry dust which has non cohesive fine particles, does not take up water during strength gain. Also, the specific surface of fly ash particles is greater than that of quarry dust particles, hence for achieving maximum dry density, more the fly ash in mix, more will be the amount of water consumed.

3. 2. Unconfined Compressive Strength (UCS) Test Figure 2 shows variation of UCS value for various fly ash – quarry dust mixes obtained after curing for 3, 7 and 28 days. The strength gain within the mixes containing fly ash is attributed to the presence of silica and alumina [30]. It was observed that as the percentage of quarry dust addition to fly ash increased, the strength of the mix decreased. This is due to addition of quarry dust increase the amount of coarser non-cohesive particles in the mix. As the amount of quarry dust increases, the formation of binding gels formed during cementation process in the class C fly ash decreases. Hence, for the C10QD mix, the UCS values are higher at 3, 7 and 28 days than other that for C20QD, C30QD, C40QD mixes. According to IRC 37 [24], the subbase material for flexible pavements must have a minimum UCS of 7 MPa after 7 days of curing. Therefore, the mix containing C10QD mix meets the requirements specified by IRC 37 [24] for the use in subbase.

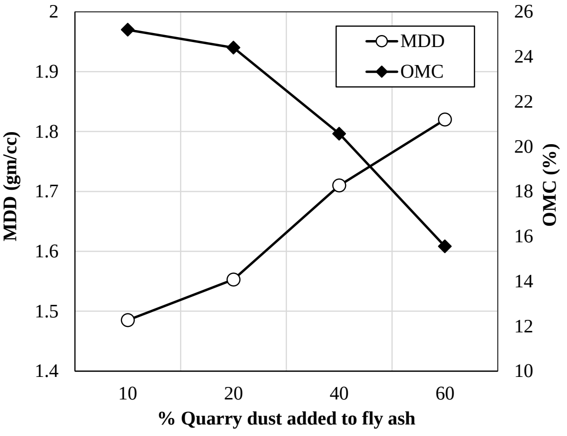

Figure 1. Maximum dry density and optimum moisture content with varying quarry dust addition to fly ash

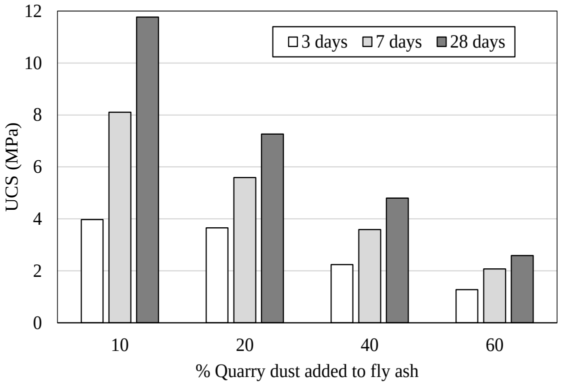

Figure 2. Variation of unconfined compressive strength with varying quarry dust addition to fly ash

3. 3. Durability Test The weight loss after 12 alternate weighting and drying cycles as per ASTM D559 [27], the % wights lost for all mixes are shown in Table 3. Weight loss during a durability test for material intended for the use as subbase of flexible pavement should not exceed 14%, following IRC 37 [24]. For its part, C10QD not only outperforms C20QD, C30QD AND C40QD in terms of durability but also meets the requirements set forth by IRC 37 [24]. C40QD does not meet the durability criteria for subbase application.

3. 4. Repeated Load Triaxial Test The C10QD mix satisfied both strength and durability criteria to be used as subbase material in flexible pavement, hence the repeated triaxial load test was performed on this mix after initial 7 days of curing and the results were compared to conventional GSB. For the subbase of typical flexible pavement, confining pressure of 34.5 kPa and deviator stress of 103.5 kPa were estimated [31]. For this reason, the resilient moduli of C10QD and GSB have been compared (see Figure 3) using the stress combination of confining pressure 34.5 kPa and deviator stress 93.1 kPa which is one of the stress combination in the testing sequence for subbase material as per AASHTO T307 [28]. The resilient modulus values were found to be

TABLE 3. Weight loss (%) for all mixes

Mix	Weight loss, %
C10QD	9.74
C20QD	11.90
C40QD	13.67
C60QD	15.83

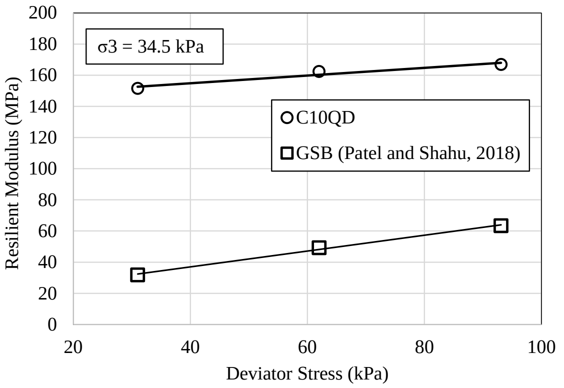

Figure 3. Comparison of resilient moduli of C10QD with conventional GSB

increasing with increment in deviator stress. This increment in MR is observed due to strain hardening phenomenon. Similar results are discussed in literature [32,33,34].

The fly ash and quarry dust mix gains strength by virtue of pozzolanic reaction. The efficiency of the binding of the quarry dust and fly ash particles increases with the amount of binding gel created during the pozzolanic reaction, and the MR value improved as a similar results reported in literature [4]. In case of conventional granular subbase material, due to absence of pozzolanic materials, no binding gel is formed. The resilient modulus values for C10QD were found to be significantly higher than that of conventional GSB material [35].

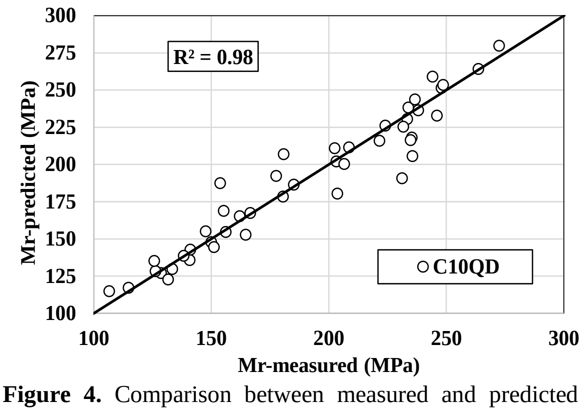

Figure 4. Comparison between measured and predicted resilient modulus values using MR– θ model for C10QD mix

For prediction of resilient modulus (MR) at different cell pressure, Equation (1) MR-θ model [4] was used as follows:

$$MR = k_1 . \theta^{k2} \quad (1)$$

where, MR – resilient modulus and θ – bulk stress.

Figure 4 shows the predicted MR vs measured MR plot. The r^2 value of 0.98 shows that the MR-θ model provides good prediction of resilient modulus. The advantage of MR – θ model is that the effect of confining stress and deviator stress is combined for prediction of resilient modulus. The model constants were found to be k_1 = 1.6387 and k_2= 0.905.

3. 5. X-Ray Diffraction (XRD) Analysis

The X-ray diffraction results for C10QD mix show prominent peaks of $Ca(OH)_2$ (portlandite), ettringite and calcium silicate hydrate (CSH). The results of X-ray diffraction are presented in Table 4. The diffraction angle (2θ) at which compunds are located are in agreement with the literature [4,3,36-39]. It can be seen from the comparison between intensities of peaks of XRD spectra that there is development of $Ca(OH)_2$, CSH and Ettringite in C10QD mix after 7 days of curing.

The quarry dust is cohesion less material having no cementitious and pozzolanic properties. Formation of ettringite causes development of early strength within mix while formation of CSH gels cause development of long-term strength [4]. Hence, it is evident that the strength gaining takes place within the mix due to hydration process due to presence of fly ash and formation of hydration products such as ettringite and CSH.

TABLE 4. X-ray diffraction peak intensities of compounds in fly ash and C10QD mix

Compound	2θ	Fly ash	C10QD (7 days)
$Ca(OH)_2$	24.77^0	0	68
$Ca(OH)_2$	33.18^0	0	129
$Ca(OH)_2$	40.95^0	0	53
CSH	15.81^0	0	59
CSH	27.47^0	0	87
Ettringite	18.99^0	0	47
Ettringite	42.44^0	0	81
CaO	54.7^0	91	57
SiO2	20.7^0	470	0
SiO2	26.9^0	1205	625
Al2O3	46.6^0	109	73

3. 6. Scanning Electron Microscopy (SEM)

The SEM images for C10QD after 7 and 28 days of curing are as shown in Figure 5. The presence of needle shaped ettringite phases and latticelike CSH phases are found in C10QD mix [40,41]. Formation of the CSH which is important cementitious phase causes binding of fly ash and quarry duct particles together causing increment in UCS and resilient modulus [8]. Formation of ettringite causes densification of structure [42]. The presence of ettringite as well as CSH is supported by XRD results.

4. PAVEMENT ANALYSIS

KENLAYER program was used to simulate and analyze conventional pavement with wet mix macadam (WMM) along with granular subbase (GSB) and proposed pavement with C10QD material at subbase provided with crack relief layer (CRL) at top. The pavement sections were assessed for 15 MSA traffic with standard axle single wheel load and 15 years design period. The details of each layer used for analysis are given in Table 5 with reference to IRC 37 [24]. Table 6 represents the details of pavement sections considered for analysis using KENLAYER program.

As per IRC 37 [24], the service life ratio (SLR) of pavement based on fatigue and rutting criteria for both conventional and proposed pavement are calculated using Equations (2) and (3) as follows:

$$\text{SLR (Fatigue)} = (\varepsilon_{t1}/\varepsilon_{t2})^{3.89} \quad (2)$$

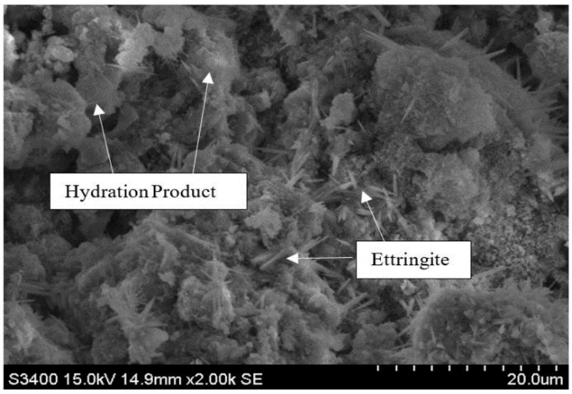

Figure 5. SEM image for C10QD mix after 7 days of curing

TABLE 5. Details of pavement sections considered for analysis

Layer	Conventional Section		Proposed Section	
	Material	Thickness	Material	Thickness
Surface	BC+DBM	110 mm	BC+DBM	110 mm
Base	WMM	250 mm	CRL	250 mm
Subbase	GSB	330 mm	C10QD	330 mm

TABLE 6. Details of pavement layers used in KENLAYER for analysis

Layer	Resilient modulus (MPa)	Poisson's ratio
BC+DBM	3000	0.35
Wet mix macadam (WMM)	450	0.35
GSB	110	0.4
C10QD	180	0.3
Subgrade	65	0.4

where ε_{t1} and ε_{t2} = maximum horizontal tensile strains, developed at the bottom of for conventional and proposed pavement, respectively. This service life ratio quantifies the relative remaining fatigue life of pavement section.

$$\text{SLR (Rutting)} = (\varepsilon_{v1}/\varepsilon_{v2})^{4.5337} \quad (3)$$

where ε_{t1} and ε_{t2} = maximum vertical strains, developed at the top of subgrade of conventional and proposed pavement, respectively. This service life ratio quantifies the relative remaining rutting life of pavement section.

The strain values at the top of subgrade and bottom of bituminous layers for conventional and proposed pavement along with SLR values are shown in Table 7.

The strain values at the top of subgrade and bottom of bituminous layers for conventional and proposed pavement along with SLR values are shown in Table 7. The proposed pavement with C10QD mix in subbase layer has 1.20 and 1.26 in fatigue and rutting SLR, respectively. This shows that the performance of proposed pavement with C10QD mix in subbase has 20% and 26% more service life in fatigue and rutting compared to the conventional pavement with GSB, respectively.

TABLE 7. SLR for subbase material GSB and C10QD

Subbase material	Fatigue strain (ε_t) × 10^{-4}	Rutting strain (ε_v) × 10^{-4}	SLR	
			Fatigue	Rutting
GSB	-2.01E-04	3.41E-04	1	1
C10QD	-1.92E-04	3.24E-04	1.20	1.26

5. CONCLUSIONS

Following conclusions can be drawn from the study of fly ash and quarry dust mixes;

The UCS value for C10QD mix was 8.105 MPa after 7 days of curing which fulfils the strength criteria for the mix to be used as subbase material in flexible pavement. C10QD, C20QD and C40QD mixes satisfied durability criteria to be used as subbase material in flexible pavement. C10QD was found to have a resilient modulus that is five times higher than that of conventional GSB material. This is because of self-cementitious properties of class C fly ash used in the C10QD mix which promotes the strength gaining within the mix. The XRD and SEM analysis for C10QD demonstrated presence of hydration product phases after curing due to which the strength gain takes place within mix. The pavement with C10QD mix in subbase demonstrated 1.20 and 1.26 SLR in fatigue and rutting, respectively compared to conventional pavement. Hence, service life of proposed pavement is more than that of conventional pavement.

The C10QD mix satisfies both strength as well as durability criteria for subbase material in flexible pavement. Class C fly ash is industrial by-product and quarry dust is waste from crushing plants, hence combined used of this material is sustainable and economical. Using such materials in road construction can lead to less consumption of natural aggregates which are depleting. Hence, it is recommended that this mix can be used in subbase layer in flexible pavement along with crack relief layer as per IRC 37 [24].

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Persian Abstract

چکیده

تهی شدن خاکدانه ها و خاک های طبیعی مرغوب، نیاز به استفاده از فرآورده های جانبی صنعتی و مواد زائد در راه سازی را می طلبد. استفاده از ضایعات و فرآورده های جانبی در راه سازی مقادیر زیادی را مصرف می کند و مشکل دفع ایمن آنها را حل می کند. خاکستر بادی کلاس C محصول جانبی نیروگاه های حرارتی است در حالی که گرد و غبار معدن زباله هایی است که در طی فرآیندهای استخراج معدن باقی می مانند. این مطالعه کاربرد خاکستر بادی کلاس C و مخلوط گرد و غبار معدن را برای استفاده در لایه زیرپایه روسازی انعطاف پذیر مورد بررسی قرار داد. خاکستر بادی کلاس C و گرد و غبار معدن با کمک آزمون مقاومت فشاری نامحدود، آزمایش بارگذاری مکرر سه محوری، آزمون دوام و تجزیه و تحلیل ریزساختاری مورد مطالعه قرار گرفت. مخلوط ۹۰ درصد خاکستر بادی به اضافه ۱۰ درصد گرد و غبار معدن با توجه به معیارهای استحکام و دوام برای استفاده به عنوان ماده زیرپایه در روسازی انعطاف پذیر مناسب است. به دلیل تشکیل فازهای سیمانی در طی واکنش پوزولانی، مخلوط پیشنهادی مدول ارتجاعی به‌طور قابل‌توجهی نسبت به مواد زیر پایه دانه‌ای معمولی نشان داد. نسبت عمر مفید روسازی با مخلوط پیشنهادی در مقایسه با روسازی معمولی در خستگی و شیار به ترتیب ۱.۲ و ۱.۲۶ است. استفاده از گرد و غبار معدن و خاکستر بادی در مقادیر زیاد در روسازی انعطاف پذیر یک راه حل اقتصادی و همچنین پایدار برای راه سازی است.