Investigation on the Suitability of Limestone Quarry Dust as an Alternative to Crystalline Rock Quarry Dust as a Filler Material in Hot Mix Asphalt Production in Sri Lanka

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Abstract – *With the recent boom in infrastructure development, especially in the road construction industry, the demand for hot-mix asphalt concrete has increased in Sri Lanka. This has created a rise in demand for hot mix asphalt concrete and thus an increase in the price of quarry dust, which is used as the filler material in hot mix asphalt concretes. As a solution to this problem, this work investigates the appropriateness of using limestone quarry dust as the filler material in place of conventionally used crystalline rock quarry dust in the production of hot mix asphalt concrete.* Results are found to be very encouraging from the inception as the *physical properties of limestone quarry dust comply with the local standard specifications as a filler material for hot mix asphalt concrete. Moreover, a Marshall Test programme was carried out to evaluate the performance of hot mix asphalt concrete blended with limestone quarry dust as a filler material, which encompassed tests such as stability, flow, voids in the mix, and percentage voids filled with bitumen of hot-mix asphalt concrete. Limestone quarry dust was replaced with crystalline rock quarry dust in percentages of 10%, 40%, 70%, and 100% by weight in the blended samples and each sample set was further tested under different bitumen contents of 5.0%, 5.3%, 5.6% and 6.0% by weight of the filler. Results reveal that all the blended samples satisfy the compliance levels for all the tested parameters specified by Standard Specifications for Construction and Maintenance of Roads and Bridges in Sri Lanka and thus can be concluded that limestone quarry dust can be used as a filler material in place of conventionally used crystalline rock quarry dust. It has also been revealed that an optimum bitumen content of 5.43% needs to be adopted if only limestone quarry dust to be used as the filler material.*

Keywords: *Limestone quarry dust, Asphalt Concrete, Filler material, Marshall Test*

Nomenclature

CQD – Crystalline Quarry Dust
HMAC – Hot Mix Asphalt Concrete
PSD - Particle Size Distribution
MT-Marshall Test
OBC – Optimum Bitumen Content
VFB – Voids Filled with Bitumen
VMA – Voids in Mineral Aggregates
LQD -Limestone Quarry Dust

1 INTRODUCTION

Hot Mix Asphalt Concrete (HMAC) is widely preferred in the road construction sector as the primary surfacing layer, due to its distinctive attributes, including cost-effectiveness, easy maintenance, durability and excellent resistance to cracking and rutting. Moreover, HMAC can be recycled and can be customized to meet specific engineering requirements. These qualities render it a reliable option for creating enduring road surfaces.

Typically, HMAC consists of a carefully blended combination of a coarse aggregate made from crushed rock or gravel (with a size greater than 2.36 mm), fine aggregate (either natural sand or crushed rock fines with a size less than 2.36 mm), filler, and asphalt cement, serving as the binding agent for the asphalt (Pandit and Roy, 2019). This combination helps to enhance the performance of asphalt pavements. Filler plays a crucial role in filling voids in the aggregate mix, thereby enhancing the density, stability, and toughness of the asphalt concrete mix. However, the inclusion of an excess amount of filler is likely to enhance the brittleness of the mixture which will induce cracking. Conversely, a shortage of filler tends to elevate the void content, resulting in the development of a softer mixture characterized by reduced stability. Therefore, it is prudent to use the ideal proportions of filler in HMACs, in considering the durability of the surfacing layer, which reduces the cost of pavement rehabilitation and maintenance (Csanyi, 1994).

The commonly used filler materials are cement, hydrated lime, and quarry dust (Rahman et al., 2012). Crystalline quarry dust (CQD), which forms in quarries of crystalline rock, typically of metamorphic origin in the Sri Lankan context, is widely employed as a filler material in Sri Lanka. This is primarily attributed to its more economical cost compared to alternative filler materials (Diyes et al., 2014). Nevertheless, the previously perceived low-cost nature of quarry dust is no longer accurate, as the material's price is currently on the rise. This increase can be attributed to its widespread utilization in concrete, mortar mixtures, and the production of bricks and blocks.

About 10 % of Sri Lanka's geological rock terrain composition consists of limestone, which belongs to the Miocene aged sedimentary category. Therefore, it is commonly used as a raw material in the construction industry (Jayawardene, 2017). A considerable amount of Limestone dust generates as waste material in the comminution process during aggregate production, which causes a huge negative impact on the ecosystem.

In contrast, the lower demand for quarry dust produced in limestone quarries in Sri Lanka makes it more economical compared to its crystalline counterpart. Therefore, this study aimed to assess the suitability of utilizing limestone quarry dust (LQD) as a filler material in the production of HMAC.

2 PREVIOUS STUDIES

Numerous studies have been carried out to evaluate the efficacy of utilizing waste materials as fillers in asphalt concrete. In this context, Diyes et al. (2014) conducted a study to assess the suitability of employing fly ash (FA) as the filler material in Hot Mix Asphalt. By employing the Marshall test (MT), which assesses the load and flow rate of asphalt specimens, the researchers determined the optimal ratios for the components of the asphalt concrete mix in a testing regime involving replacements of 100%, 58%, and 42% (corresponding to 12%, 7%, and 5% of the total weight of aggregates), mineral filler substituted with fly ash. According to their findings, FA obtained from the waste generated in the Norochcholai Coal Power Plant is found to resemble the particle size distribution of a conventional mineral filler, with a slightly lower specific gravity and a slightly higher fineness compared to quarry dust. They have been able to successfully replace 42% (equivalent to 5% of the total weight of the aggregates) of the mineral filler by FA to yield a mixture that surpasses the minimum stability requirement (8 kN) and with an optimum bitumen content (OBC) of 5.5% (by weight of the aggregates) criteria meeting the specified guidelines in the Construction Industry Development Authority (CIDA, 2009).

Mistry and Roy (2016) conducted a similar type of study on FA as the filler material for HMAC with the waste FA from a thermal power plant. By carrying out a MT programme of different bitumen contents (3.5−6.5% at 0.5% increments) with 2% hydrated lime and varying FA replacement of 2% to 8% with the mineral filler, they were able to successfully replace with a 4% (of the total weight of aggregates) FA to obtain a HMAC of higher stability with lower OBC, satisfying their local regulatory specifications.

Saw dust ash (SDA) as a filler material is found to produce promising results when it is replaced with the original basaltic stone dust filler (Fayissa et al., 2021). In a test programme of 3% to 12% replacement in 3% increments of SDA in place of basaltic dust, the best results were produced at a 12% replacement level. The OBC obtained at this replacement level met the local regulatory standards, and optimal outcomes are observed for both tensile strength and fatigue performance at this replacement level as well. The addition of SDA has improved the fatigue life of HMAC, and an increased concentration of calcium carbonate in SDA has reduced the potential for moisture damage. Nevertheless, basaltic stone dust was still found to perform well compared to SDA with respect to most of the MT parameters, including stability and OBC.

Jony et al., (2011), have investigated three types of filler materials, viz., limestone dust (LD), Ordinary Portland Cement (OPC), and glass powder (GP) in their study. They found that the optimal replacement level for GP is 7% of the total aggregate weight when used with conventional mineral filler. Out of the three filler material options they have investigated, a notable increase of stability up to 13% and a decrease in flow and density to 39% and 10% respectively is reported in HMACs with GP, when compared to LD and OPC. These results have been produced in a test programme of filler replacement in 4%, 7%, and 10% by weight of total aggregate.

Tire-derived fuel fly ash (TDFFA), which mainly constitutes CaO and SiO_2 is also can be effectively replaced in place of mineral fillers in HMACs (Choi et al., 2020). Choi et al., (2020) carried out a study to investigate the filler suitability of TDFFA, cement, stone dust (SD) and hydrated lime (HL) in HMACs. Choi et al., (2020) further reports that the addition of TDFFA has caused to increase in the stripping resistance, and the degree of coating and hence causes an increase in the peeling resistance by exertion of a uniform bonding force between the asphalt and the aggregate by the spherical particles of the TDFFA. Moreover, the tensile strength ratio (which is used as a parameter to measure the moisture resistance of a mineral filler) of TDFFA is found to be greater compared to cement and SD, thus implying that TDFFA effectively improves the moisture resistance. In addition to the compliance with the basic Korean specifications, the HMACs which use TDFFA were also found to satisfy the local criteria on dynamic stability.

According to research conducted by Choudhary et al. (2020), it was found that Limestone sludge (LS) generated in the dimensional limestone industry exhibits outstanding performance as a filler in HMAC. Particularly noteworthy are its superior qualities in essential parameters such as rutting resistance, fatigue resistance, indirect tensile strength, and resilient modulus when compared to HMACs containing conventional fillers. This was revealed during a testing programme of MT and OBC, where LS was substituted at varying percentages of 4%, 5.5%, 7%, and 8.5% by weight of aggregates. The results indicated that the optimal filler percentage for LS was determined to be 6.45%.

3 METHODOLOGY

As the initial step, the conformity of the conventional filler material, CQD, and the alternative material, LQD, with standard specifications was examined. For this, particle size distribution (PSD), specific gravity, and water absorption tests were carried out to evaluate their adherence to established standards.

Secondly, Marshall Tests (MT) were conducted on both a control sample (solely comprised of CQD) and blended samples (mixed with varying proportions of LQD). This aimed to acquire Marshall parameters, including stability, Marshall flow, air voids in the mix, voids in mineral aggregate (VMA), and voids filled with bitumen (VFB). Subsequently, the attained Marshall parameters were compared with the prescribed levels outlined in accordance with the CIDA guidelines.

3.1 Materials

To facilitate the preparation of HMAC in this study, metamorphic aggregates of two specified sizes were employed: Coarse aggregates, denoted as Type 1 (20mm), and medium-sized aggregates, denoted as Type 2 (5mm). Additionally, Type 3 aggregates with a finer granularity of 2mm were also utilized. These were employed as the conventional filler material (CQD). The asphalt binder used was 60/70 pen-grade bitumen. To prepare the blended samples, LQD was obtained from the Aluvihare limestone quarry in Matale. As the binder in preparation for HMA, grade 60 penetration bitumen was used.

3.2 Tests and Standards

The PSD for CQD aggregates Type 1, Type 2, Type 3, and LQD was conducted using a sieve analysis test as per BS 812-103.1:1985, while the specific gravity test and water absorption tests were conducted according to BS 812:1995: Part 2 standards. For the control sample as well as for the blended HMACs, conventional MTs were carried out according to the specifications stipulated in the standard AASHTO T245- 97, (2001).

Initially, coarse aggregate, fine aggregate, and filler were proportioned according to the specified standards. A quantity of around 1250g of the mix was selected to make the compacted bituminous specimens with an approximate thickness of around 65-70mm. Aggregates were heated to a temperature range of 175°C to 190°C, while simultaneously, the compaction mould assembly and rammer were cleaned and preheated to temperatures between 100°C and 145°C. The bitumen was also heated to a temperature in the range of 121°C to 138°C. In the initial bitumen trial, the required amount was added to the heated aggregates and thoroughly mixed to achieve uniformity. The resulting mix was placed in a mould and compacted with 75 blows for each side from the rammer. Following compaction, the sample was swiftly extracted from the mould using a sample extractor within a very short period.

3.3 Sample Preparation

HMAC samples were made as per Marshall Mix Design procedure and the blended samples were prepared by replacing the CQD with LQD for filler content as per table 1 given below.

LQD percentages for filler were selected based on previously conducted research to assess the possibility of completely replacing CQD with LQD.

Table 1 Different blends of HMA with LQD as filler

% of Bitumen by weight	Experimental Programme			
5	100% LQD	30% CQD, 70% LQD	60% CQD,40% LQD	90% CQD,10% LQD
5.3	100% LQD	30% CQD, 70% LQD	60% CQD,40% LQD	90% CQD,10% LQD
5.6	100% LQD	30% CQD, 70% LQD	60% CQD,40% LQD	90% CQD,10% LQD
6	100% LQD	30% CQD, 70% LQD	60% CQD,40% LQD	90% CQD,10% LQD

Bitumen percentages were obtained according to CIDA (2009) specifications and by considering the workability during the HMAC sample preparation.

The physical properties of aggregates and fillers are shown in Table 2. The performance criteria (stability, flow, voids in the mix, voids in the aggregate, percentage voids filled with bitumen) of different blends (mixtures) of hot mix asphalt made with LQD are assessed and compared with that of Sri Lankan local authority's conventional asphalt concrete standards.

4 RESULTS AND DISCUSSION

Results of PSD, specific gravity, and water absorption for CQD and LQD are given in Table 2 and Figure 1.

Table 2 Specific gravity and water absorption test results of CQD and LQD

Materials	Specific gravity	Water absorption (%)
Type 1 (CQD)	2.86	0.45
Type 2 (CQD)	2.80	0.20
Type 3 (CQD)	2.82	0.20
LQD	2.76	0.76

Utilizing the PSD results, a control HMAC sample was made in triplicate (Sample 1, Sample 2, and Sample 3) using the conventional CQD material, maintaining the same mixing ratios to investigate their mixing uniformity. The uniformity of mixing was assessed in accordance with ICTAD specifications for PSD in Table 2 and Fig. 2. Consequently, all three samples were found to meet the ICTAD specifications.

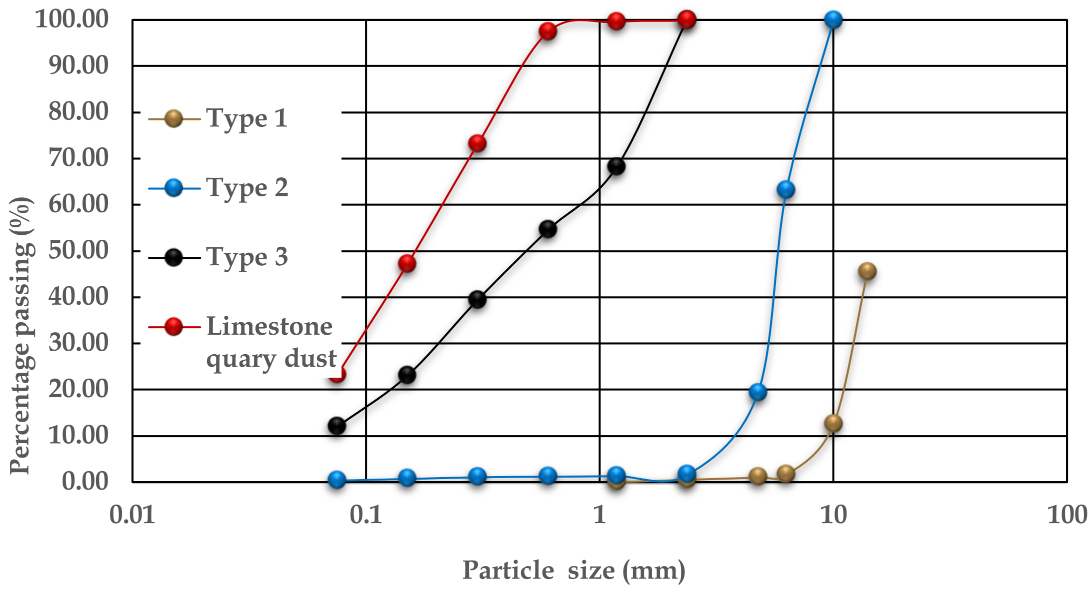


Figure 1. PSD curves of conventional aggregate materials (CQD) and LQD

Table 3 PSD results for aggregate sample mixtures

Sieve size (mm)	% passing			Grading Requirement as per CIDA Specifications (%)
	Sample 01	*Sample 02*	*Sample 03*	
10	75.87	74.30	74.24	56 - 82
5	57.89	55.61	55.39	36 - 58
2.36	42.87	40.98	39.73	21 - 38
1.18	35.13	33.28	32.58	15 - 32
0.6	27.58	25.36	24.76	10 - 26
0.3	19.71	17.94	17.51	6 - 20
0.15	11.66	11.07	11.01	3 - 13
0.075	4.98	4.51	5.08	1 -7

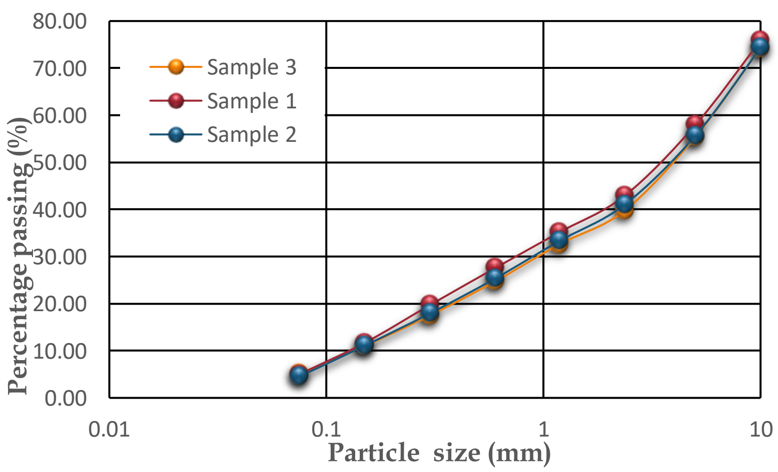


Figure 2. PSD curves for aggregate sample mixtures

As the next step, material passing from the 0.15 mm size sieve corresponding to Sample 01 was replaced with LQD as described in section 3.2 and proceeded with the MTs to check the CIDA compliance criteria. MT results are given in Table 3 with relevant CIDA compliance levels and Fig.3 to Fig.7 depict the variation of different Marshall parameters against different binder contents at different LQD replacement levels.

According to the graphical behaviour reported in Fig. 3, the stability of HMAC increases with increasing asphalt binder content and produces a post-peak decline, thus creating an optimum binder (bitumen) content to adopt in HMAC mix designs.

Flow is defined as the vertical deformation during the test. The curves in Fig. 4 indicate a general increase in flow as bitumen content rises. Notably, the results consistently met the compliance levels. It is crucial to emphasize that, under these conditions, the minimum value must stay within the specified limit to prevent the mixture from becoming excessively stiff. Concurrently, the maximum value should remain within the limits to prevent the mixture from being too soft and ensure its ability to withstand expected traffic loads. Adhering to these prescribed limits will ensure the optimal performance and durability of the asphalt mixture under various traffic conditions.

Table 4 Marshall stability test results for blended asphalt concrete with LQD

Replacement level of LQD as the filler in place of CQD	Stability (kN)	Flow (0.25mm)	Air voids (%)	VMA (%)	VFB (%)
100%	8.79	10.32	4.43	16.75	73.54
	10.56	12.04	3.98	17.00	76.61
	10.50	13.4	3.83	17.51	78.13
	8.33	14.96	3.73	18.28	79.58
70%	9.09	9.76	4.11	16.30	74.80
	11.24	11	3.83	16.70	77.07
	11.14	12.6	3.73	17.27	78.42
	8.75	14.44	3.54	17.96	80.31
40%	10.34	8.96	3.66	15.92	77.00
	12.71	9.92	3.51	16.43	78.62
	12.11	11.36	3.38	16.94	80.03
	10.41	13.52	3.19	17.65	81.90
10%	11.91	8.2	3.40	15.80	78.51
	14.00	9.2	3.26	16.33	80.05
	12.74	10.28	3.21	16.91	81.02
	10.74	13.56	3.18	17.77	82.11
CIDA Specifications for High Traffic CNSA > 10^6	Not less than 8	8 to 16	3 to 7	>14	-

The air void content decreases against increasing bitumen content, which matches the expected theoretical behaviour of these parameters as depicted in Fig. 5.

As depicted in Fig. 6, VMA levels gradually increase with increasing bitumen content. When VMA values are high, it implies that more space is available for the binder. As Table 3 reveals, VMA levels surpass the compliance limits, affirming the sufficient durability of the specific HMACs.

VFB increases with increasing bitumen content while decreases with the addition of LQD in Fig.7. Hence, this suggests that an excessive amount of LQD diminishes the effective thickness of bitumen, leading to the formation of a less durable HMAC.

The optimum binder contents, which produce maximum stability levels corresponding to the respective replacement levels of LQD are obtained using the stability curve presented in Fig.3, as the other parameters are within the limits of CIDA specifications. Table 4 presents the optimum bitumen contents to be adopted under different LQD replacement levels as filler material in HMACs.

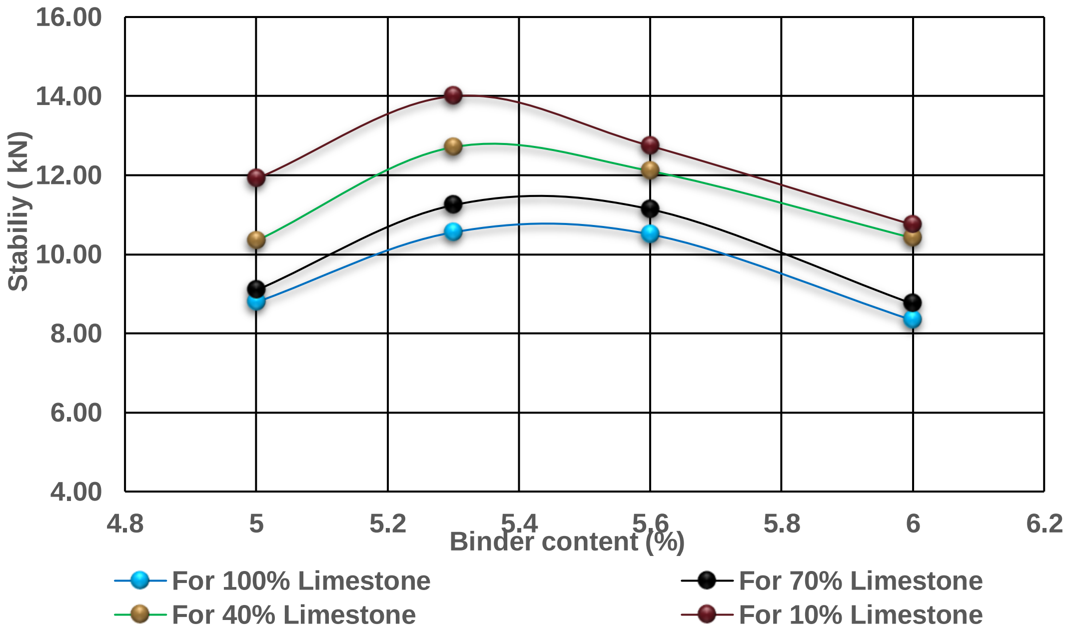


Figure 3. Stability variation in HMAs with binder content under different filler replacement levels of LQD

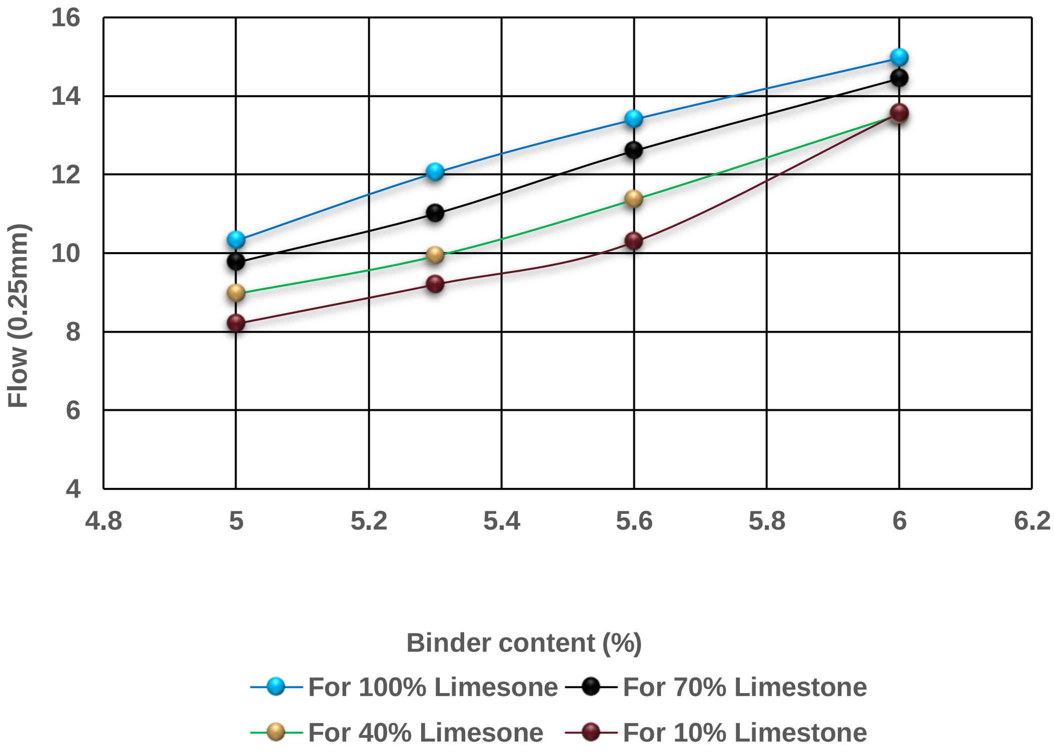
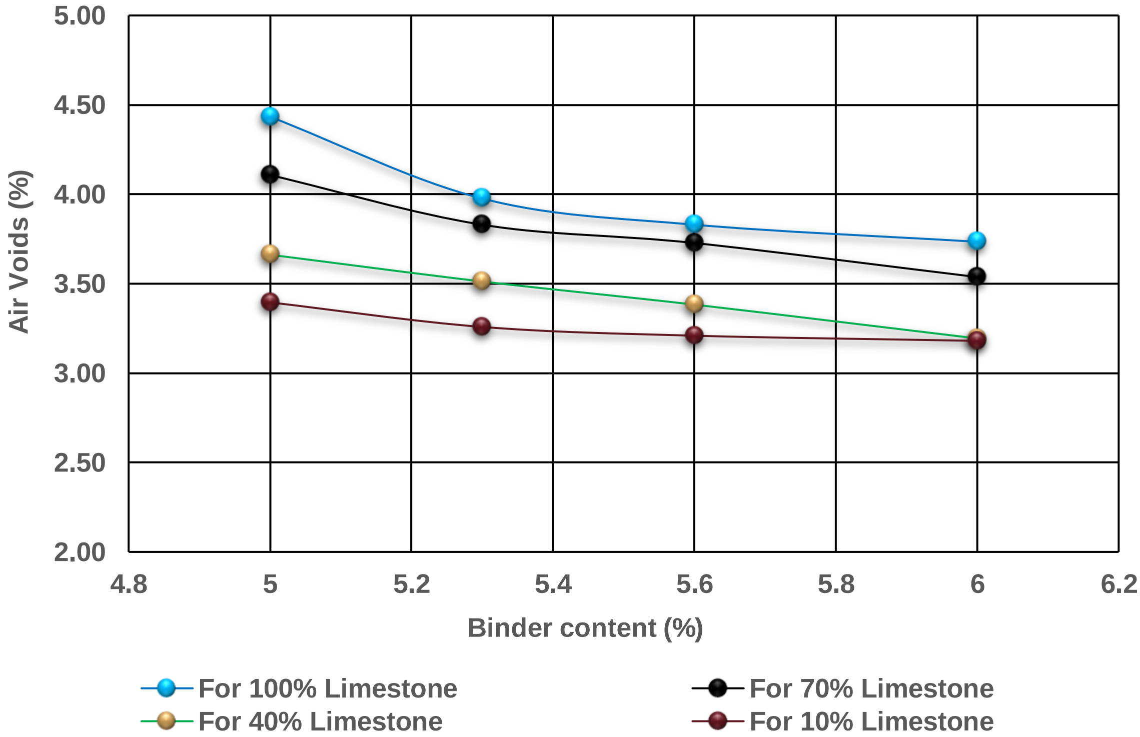


Figure 4. Flow variation in HMAs with binder content under different filler



replacement levels of LQD

Figure 5. Air void variation in HMAs with binder content under different filler replacement levels of LQD

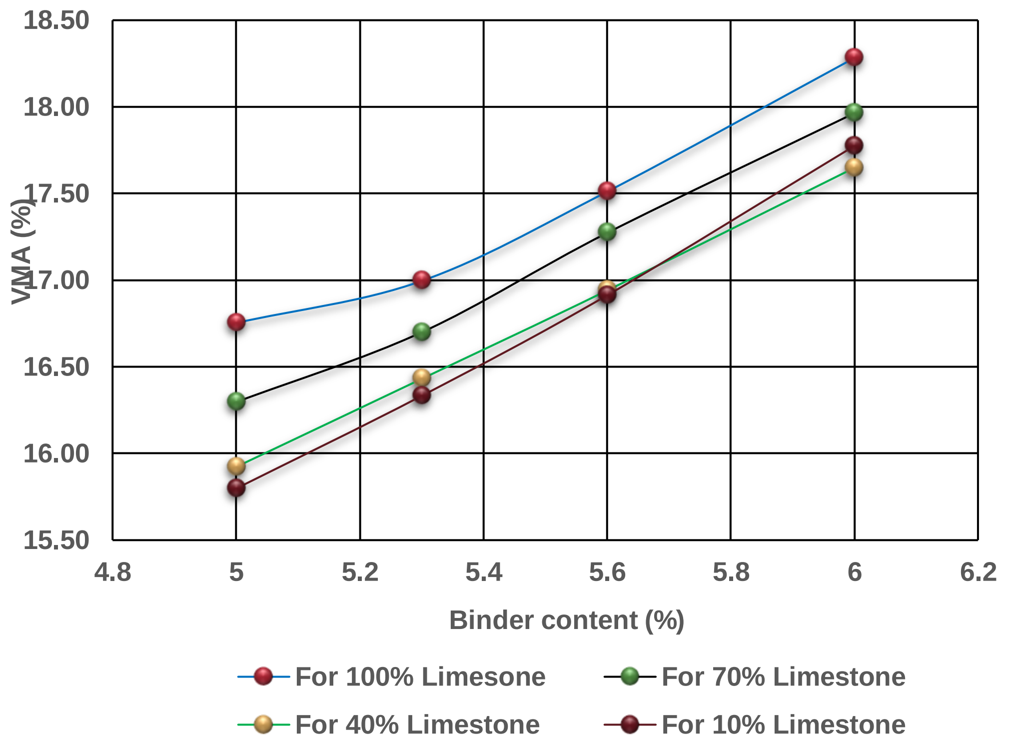


Figure 6. Voids in mineral aggregate variation in HMAs with binder content under different filler replacement levels of LQD

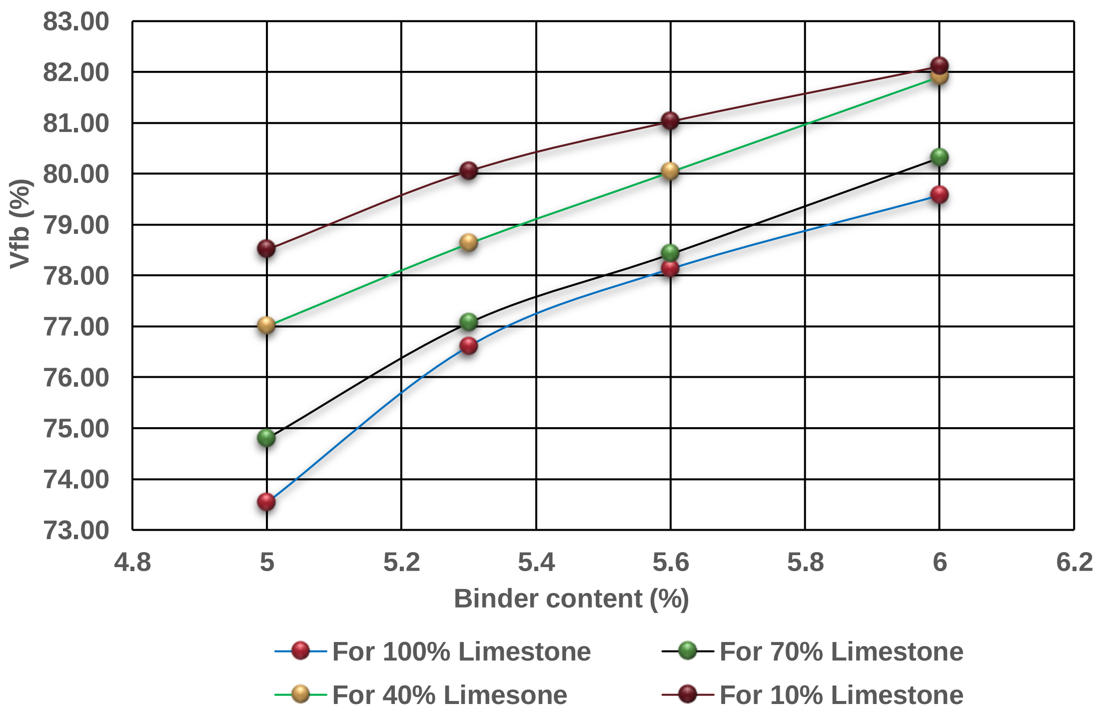


Figure 7. Voids filled with bitumen variation in HMAs with binder content under different filler replacement levels of LQD

Table 4 Optimum bitumen content for different mixes

Mix proportion of LQD as filler	Optimum bitumen content (%)
100%	5.43
70%	5.42
40%	5.36
10%	5.32

Table 5 (a) Summary of Material Properties

Name of the Test	Type 1 crushed stones	Type 2 crushed stones	Type 3 crushed stones	LQD	CIDA specification
Sieve Analysis Test	As per Table 3, all the aggregate types as well as blended samples were within the specified grain size standards.				
Specific gravity(g/cm^3)	2.86	2.8	2.82	2.76	>2.75
Water absorption	0.45	0.2	0.2	0.76	<2

Table 5 (b) Summary of Martial Parameters

Marshall parameters	Average values for blended samples with LQD as filler				CIDA Compliance levels
Percent of LQD filler	100%	70%	40%	10%	
Stability (kN)	9.55	10.06	11.39	12.35	>8
Flow (mm)	12.68	11.95	10.94	10.31	8-16
Air voids (%)	3.99	3.80	3.44	3.26	3-7
VMA (%)	17.39	17.06	16.74	16.7	>14
VFB (%)	76.97	77.65	79.39	80.42	

5 CONCLUSIONS AND RECOMMENDATIONS

Following conclusion can be made based on the summary of results presented in Table 5(a) and Table 5(a).

The PSD, specific gravity, and water absorption results fall within the stipulated compliance limits set by the CIDA specifications. Marshall test results for both the control sample and blended samples affirm the viability of substituting LQD as a suitable alternative to conventionally employed CQD as the filler material in HMAs. All Marshall Test parameters consistently fall within the CIDA compliance levels designated for asphalt concrete.

The main progressive finding made in this study is the recognition that locally available LQD not only can be used as a partial replacement of CQD but also as an alternative material that can even completely replace CQD in using as a filler material in HMAs.

In the case of using LQD as a complete alternative filler material in HMA, a bitumen content of around 5.43% can be recommended.

In practical HMAC production, it is typical to encounter situations which create a common shortfall of 1% to 2% in filler material, particularly when employing CQD as the filler material. Based on the aforementioned findings, it can be inferred that the relatively lower specific gravity of LQD requires a correspondingly larger volume of LQD. Therefore, if HMACs can be manufactured solely using LQD, such a shortfall filler material may not arise, as there would be an abundance of fine material in the HMAC compared to an HMAC produced with CQD. This, in turn, could contribute to a reduction in production costs.

This study has been carried out to assess the suitability of incorporating LQD as a filler material in the production of HMACs. Based on the findings, it is suggested to conduct additional investigations to explore the viability of substituting coarser grades of limestone quarry aggregates for the larger size ranges of crystalline rock aggregates in HMAC production.

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