

Performance evaluation of coal dust and wood powder ash as alternates of conventional filler in the asphalt concrete

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Abstract

Mineral fillers provide a significant role in the Marshall properties of hot mix asphalt for paving applications. The article's goal is to assess the suitability and effectiveness of two minerals (coal dust and wood powder ash) used as fillers in asphalt concrete. Chemical composition test using X-ray fluorescence indicated a high content of SiO₂, Fe₂O₃, and Al₂O₃, which encouraged us to select the coal dust and wood powder ash as mineral fillers for further investigation. A total of 90 cylindrical Marshall Specimens, made with different percentages (i.e., 4%-8%) of coal dust, wood powder ash, and conventional stone dust filler were prepared to assess the performance of individual filler within the asphalt concrete mix. And after that, volumetric characteristics such as density, stability-flow test, air void, and voids in mineral aggregates have been analyzed to evaluate the effectiveness of every sample and, afterward, to find out the optimum asphalt content. Finally, the optimum asphalt content for every filler material was ascertained, and subsequently, Marshall properties were checked again to assess the optimum filler content in the mix that satisfy all the standard criteria. The overall Marshall properties for both fillers were within the acceptable limits. Though the optimum asphalt content was higher for coal dust than wood powder ash and stone dust, the wood powder ash showed better durability than coal dust. All mixtures have been found to have better resistance to deformation, fatigue, and moisture-induced damages; however, 4% coal dust and 6% wood powder ash satisfied most of the Marshall criteria than other percentages.

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Keywords: Coal dust, Wood powder ash, Mineral filler, Asphalt concrete, Marshall properties

1. Introduction

Asphalt concrete comprising coarse aggregate, fine aggregate, and filler covering the blacktop layers of flexible road pavement. Fillers are commonly fine dust with grain sizes ranging from zero to hundred μm , which play an essential part in the properties of bituminous concrete. A percentage of the filler material containing particles larger than the asphalt film will contribute to the formation of connection points for both mineral aggregates. Simultaneously, the filler also serves as a colloidal dispersion inside the asphalt, ensuing the binder with a firmer consistency [1]. Its primary function is to create a dense mixture by stuffing gaps in the aggregate skeleton and enhancing the cohesion of the asphalt binder by ensuring the stability of the mix [2]. An acceptable amount of mineral filler has been used to improve moisture serviceability [3], resilient modulus [4], permanent deformation [5], fatigue cracking [6, 7], and resistance to rutting [8] for the upper layer of the flexible pavement (surface course). Conventionally, cement, stone dust (hereafter referred to as SD), and lime are used as fillers in subtropical monsoon climatic regions [8]. However, there is an increasing interest in using waste substances in

recent decades due to growing environmental concerns in developing countries. Industrial and by-product waste can efficiently be used as non-conventional fillers in asphalt concrete to enhance performance rather than conventional filler [9, 10, 11]. Table 1 listed some non-conventional filler names in several previous studies to check their suitability on asphalt concrete.

Table 1. List of some previous studies on the properties of asphalt concrete considering waste substances as replacements for conventional filler

Filler name	% Filler	Properties	Optimum asphalt content (%)	Optimum filler content (%)	Reference
Fly ash	2, 4, 6 & 8	Marshall Properties and Marshall Quotient	5.07, 4.9, 4.8 and 5.4	4	[12]
Fly ash	4, 5, 6, 7 & 8	Marshall Properties and Retained Stability	5.65, 5.65, 5.65, 5.70 and 5.70	6	[14]
Cement bypass dust	5 and 13	Marshall Properties	4.4 and 5.7	4	[13]
Brick dust	4, 5, 6, 7 & 8	Marshall Properties and Retained Stability	5.72, 5.67, 5.73, 5.70 and 5.65	6	[14]

Several studies were conducted to assess the suitability of using mineral filler composition on the performance of hot mix asphalt (HMA). Different types and quantities of filler affect the effectiveness of the asphalt mix [15]. For instance, notable improvement was reported on the responsive performance of asphalt mixture containing cement fillers, which include raveling rigidity and anti-permeable capacity with a 5% optimum asphalt/aggregate ratio [16]. Another study suggested better performance with 5% cement bypass dust (CBPD) filler with 4.5% optimum asphalt content without any adverse effect on Marshall properties [13] Raja and Tapas [12] revealed a relatively high stability value with a relatively low OAC for the mixture containing 4% fly ash as optimum filler content compared to conventional mix and standard specification. Arabani et al. [17] demonstrated that waste glass powder and waste brick powder show longer fatigue resistance and better perform better than others as a filler material. Mohammad and Fadhil [7] investigated that the asphalt mixes prepared with hydrated lime (Optimum Asphalt Content (OAC)-5.3%) have superior resistance to moisture damage with a higher stability value (i.e., 12.8 kN) in comparison with Portland cement (OAC-5%) and limestone dust (4.7%). However, mixtures prepared with Portland cement as a filler demonstrated greater resistance to fatigue failure of asphalt concrete pavement.

The filler materials should contain the sum of SiO_2 , Al_2O_3 , and Fe_2O_3 more than 70% as per ASTM C618[18, 19]. A primary investigation was performed in this study using X-ray fluorescence (XRF) test of individual mineral fillers to determine the percentage of SiO_2 , Al_2O_3 , and Fe_2O_3 in coal dust (hereafter referred to as CD) and wood powder ash (hereafter referred to as WPA). Table 2 shows the chemical composition test results of CD and WPA showing a relative comparison with conventional filler SD. More significant percentage of the summation of SiO_2 , Al_2O_3 , and Fe_2O_3 were found in CD and WPA than recommended values as well as than conventional stone dust (SD) that motivated us to check the further feasibility of using CD and WPA as filler material in asphalt concrete mix.

Table 2. Chemical composition test results of the selected filler materials in this study

Material	Weight percent		
	SD	CD	WPA
SiO_2	58.0516	48.0205	72.5811
Al_2O_3	10.4144	14.8643	0.7947
CaO	7.6344	11.3005	12.4044

Material	Weight percent		
	SD	CD	WPA
Fe ₂ O ₃	11.2939	9.3019	0.9900
SO ₃	0.2314	9.2584	1.0606
TiO ₂	1.4801	2.9936	0.1687
K ₂ O	3.9270	1.7389	6.7395
MgO	4.3189	1.1718	1.6793
Na ₂ O	1.9247	0.3025	0.5573
SrO	0.0298	0.2628	0.0568
P ₂ O ₅	0.4163	0.2528	2.5817
BaO	0.0824	0.1894	-
MnO	-	0.1345	0.2995
Cr ₂ O ₃	0.0321	0.0759	0.0160
ZrO ₂	0.0794	0.0569	-
ZnO	0.0535	0.0352	0.0369
CuO	0.0126	0.0226	0.0063
Rb ₂ O	0.0175	0.0175	0.0272
Total	100	100	100

Most non-conventional fillers cannot be used directly [17, 20, 21], but CD has been used in this study directly without any processing. Moreover, in Bangladesh, coal and wood powder can be easily collected. These ashes are usually the forms of fine particles that efficiently fly by air, thus causing air pollution and human health problems. The initiative to use these materials as filler material could have a sizeable impact on the environment and the economic system.

Therefore, there is a significant opportunity to develop an alternative type of mineral filler material that will provide satisfactory results while also helping to solve the environment's solid problem of waste management. Based on the background described above, the research explored the properties of asphalt concrete using CD and WPA as mineral fillers, as well as optimized the percentage of mineral fillers in asphalt concrete. Finally, we discovered correlations between OAC and the percentage of mineral fillers used.

2. Materials and methodology

Locally accessible ingredients were considered to carry out the laboratory experiments, including coarse aggregates made of stone chips, fine aggregates made of a combination of stone chips and local sand, mineral fillers (CD, WPA, and SD), and asphalt binder. Asphalt concrete mix containing stone dust filler is used as a reference/control specimen to compare the properties of CD and WPA containing asphalt mixes. The experimental investigations of this study consist of three steps, i.e., i) selection and preparation of materials, ii) physical and chemical testing of materials and iii) preparation and selection of mix proportions of materials for asphalt concrete.

In the first step, this study evaluates different asphalt concrete components to select suitable material for the experimental preparation. The brief of the materials composition and percentage of varying filler materials used in this experimental study with their AASHTO recommended percentages are provided in Table 3. In this research campaign, CD has been used as a filler material that is a powdered form of coal produced via the grinding of coal. While wood powder ash (WPA) is a form of wooden powder made via the burning of wood powder at (220 to 300)°C temperature.

Table 3. Materials composition used in this study

Materials	Study experimental setup		Standard as per AASHTO T27 and T37 [22,23]
	Sieve size	% by volume	
Stone chips (CA)	Retained on #10 and passing 3/4", 1/2", 3/8" and #4	56, 57, 58, 59 and 60	(50-65) %
Stone chips and local sand (FA)	Retained on #200, #80, #40 and Passing #10	36	-
Fillers (SD, CD, WPA)	Passing # 200	4, 5, 6, 7 and 8	(4-8) %
Asphalt binder		5-7 (60/70 PG)	5-8

Subsequently, in the second step, the physical properties of aggregate and asphalt binder were checked as per the standard guidelines and compared with typical values to cross-check the appropriateness of selected materials for Asphalt concrete mix. Tests such as specific gravity, absorption capacity, grain size analysis, elongation index (EI), flakiness index (FI), aggregate impact value (AIV), and aggregate crushing value (ACV) were performed to specify aggregate's physical properties. The physical properties test results of aggregates are shown in Table 4.

Table 4. Physical properties of aggregates used in this experimental investigation

Property	Test Method	Test avg. value (Coarse Agg.)	Test avg. value (Fine Agg.)	Standard value
ACV (%)	BS812: Part 110:1990 [24]	26	-	<30
AIV (%)	BS812: Part 112:1990 [25]	9.0	-	<25
Specific gravity	ASTM C 127, C 128 [27, 28]	2.64	2.59	-
EI (%)	ASTM D 4791 [29]	15	-	<25
FI (%)	ASTM D 4791 [29]	22	-	<25
Water Absorption (%)	ASTM C 127 [27]	1.19	2.10	-

A variety of laboratory tests have been conducted to evaluate the physical properties of asphalt, including resistance to degradation [26], specific gravity, ductility, flash point, fire point, softening point, and penetration. The brief test results of those tests are given in Table 5.

Table 5. Physical properties of asphalt binder used in this study

Property	Test Method	Test avg. Value	Standard Value
Penetration value	ASTM D5-86 [30]	65	60-70
Softening point (°C)	ASTM D36-70 [31]	51.5	30°C to 80°C
Specific gravity	ASTM D70-97 [32]	1.01	1.01-1.06
Flash and Fire point	ASTM D92-90 [33]	330°C, 360°C	175°C (Min. flash point)
Solubility	ASTM D2042 [34]	98.8%	-
Ductility	ASTM D113-86 [35]	100+	100 (Min.)

In the third step, 90 cylindrical experiment samples were made in accordance with the Marshall test requirements and the AASHTO medium traffic load guideline [37]. For varying asphalt content (as mentioned in Table 3), the specimen size was considered 101.6 mm (dia) \times 63.5 mm (height) by having applied 50 blows towards each edge of the cylindrical casing. The specimen compositions are shown in Table 6 and subsequently, Marshall tests were carried out in accordance with ASTM D1559 for each specimen [36]. The cylindrical Marshall samples were squeezed at a steady rate of 50.8 mm/min here on the anterior side until failure was reached and the stability, flow value, air void, void in mineral aggregates, etc. were considered to ascertain the strength and volumetric properties. Furthermore, the optimum asphalt content (OAC) was obtained.

Table 6. Specimen compositions used in this study

Filler Content (%)	Number of Specimen Containing		
	SD (Control)	CD	WPA
4	6 (CA-58%, FA-36%)	6 (CA-58%, FA-36%)	6 (CA-58%, FA-36%)
5	6 (CA-57%, FA-36%)	6 (CA-57%, FA-36%)	6 (CA-57%, FA-36%)
6	6 (CA-56%, FA-36%)	6 (CA-56%, FA-36%)	6 (CA-56%, FA-36%)
7	6 (CA-55%, FA-36%)	6 (CA-55%, FA-36%)	6 (CA-55%, FA-36%)
8	6 (CA-54%, FA-36%)	6 (CA-54%, FA-36%)	6 (CA-54%, FA-36%)
Total Samples	30	30	30

3. Results and discussion

In this research, we put our effort into ascertaining the influence of non-conventional mineral fillers (i.e., CD, WPA) on the properties of asphalt mix adding various combinations of asphalt content and mineral fillers. In order to accomplish the research objectives, we also used conventional stone dust filler material to evaluate the performance of CD and WPA. We first explored the volumetric and marshal properties of an asphalt concrete mixture specimen critical for an asphalt concrete mix to accomplish our research objectives. The optimum asphalt content on every mineral filler was then determined.

3.1. Volumetric properties of the mixture

Figure 1 shows the densities of Marshall Specimen with various binder content for the case of SD (Fig. 1a), CD (Fig. 1b), and WPA (Fig. 1c). The specimen density initially consistently increases with the increase of asphalt content overall varieties of filler materials. However, a declining trend of density was observed for SD and WPA as the asphalt content exceeds 6% and 6.5 %, respectively. Besides, a drain-down of asphalt was observed visually at an asphalt content of 7%. Drain-down is considered to be that portion of the asphalt binder that separates itself from the sample. Exceptionally, specimens containing a CD filler did not show a decreasing trend of density up to an asphalt content of 7%. This phenomenon might be attributed due to the robust absorptive nature of specimens containing CD filler. Besides, in our study, the densities of CD and WPA mixtures are less than the conventional mix using SD filler. As a result, the CD mixture shows less durability than WPA. According to Kareem and Chandra [40], the fatigue life also increases with an increase in the density of the mix. A review was carried out through Yasanthi et al. [38] reported decreasing strength properties of

asphalt concrete by adding sawdust ash (SDA) as filler. They found that the unit weight of control, 30g, and 50g SDA added samples are 2290 kg/m³, 2000 kg/m³, and 1790 kg/m³ at optimum asphalt content (OAC) 5.28, 5.50 and 5.20, respectively. Kar et al. [11] showed that an addition of 5% fly ash as a filler could result in a unit weight of Marshall specimen as 2560 kg/m³ at 5.2% OAC.

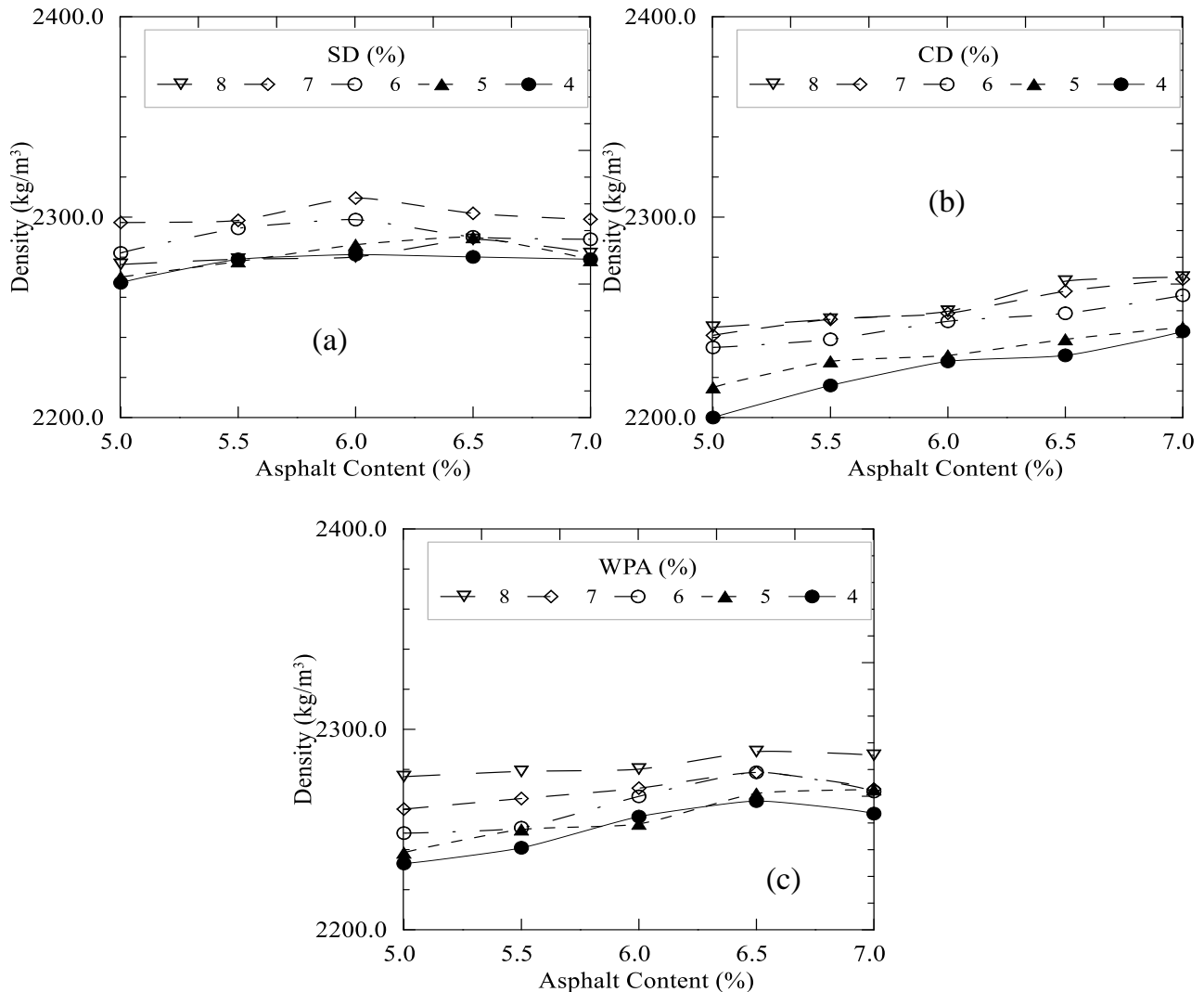


Figure 1. Variation of density with respect to the asphalt contents for mixes with different fillers used in this study

Figure 2 depicts the stability values of Marshall samples at various asphalt content levels for SD (Fig. 2a), CD (Fig. 2b), and WPA (Fig. 2c). At a standard test temperature of 60°C, the stability value means the maximum load that the compacted sample (of asphalt) can withstand. In general, a higher stability value indicates greater strength. The analysis shows that as the asphalt content increases, the stability values increase until they reach a maximum. After that, as the asphalt content increases, the stability gradually decreases. However, all specimens show better stability at 6% asphalt content. Stability values are correlated with specimen densities. It was ascertained that the stability of the sample increased with the increase density with the exception of CD samples at 6.5 and 7.0% asphalt content. Fig. 2 as well demonstrates that at 6% asphalt content, all of the test samples have better stability. This is due to the fact that lower asphalt content results in more empty spaces. As the asphalt content increases, the gaps are filled, resulting in dense-graded mixtures. Muniandy et al. [19] used coal fly ash as a filler at 10% (by weight of total aggregate). They discovered that the specimen's stability value at OAC was 6.5 kN. The mixes containing fly ash as a filler have slightly inferior properties when compared with the control mixes, but they reach the required criteria.

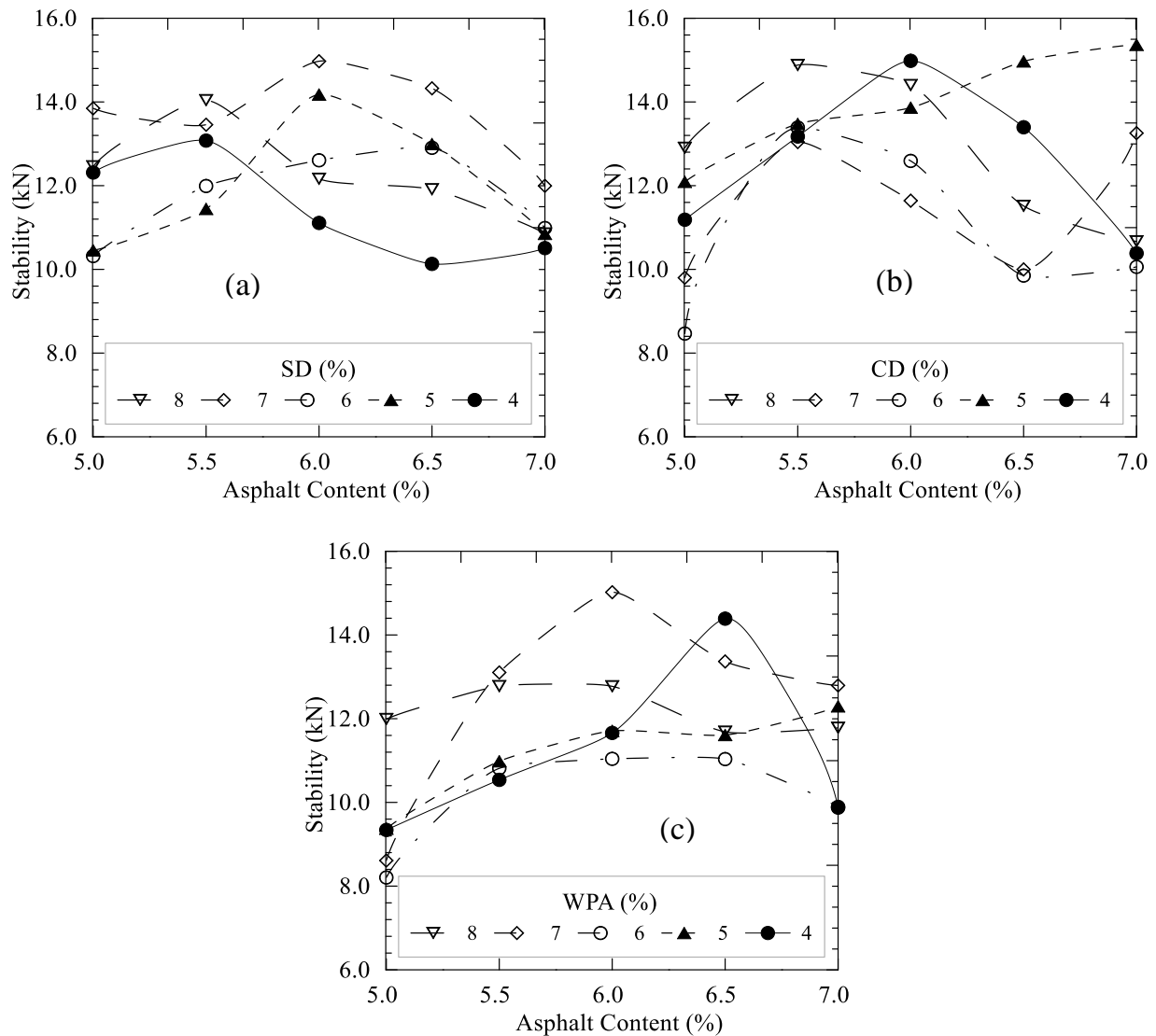


Figure 2. Variation of stability with respect to asphalt content for mixes with different fillers used in this study. Kar et al. [11] used 5% (by weight of total aggregate) coal fly ash as a filler, and the specimen had a stability value of 14.1 kN at 5.2% asphalt content. On the other hand, Mistry and Roy [12] was using variable fine aggregate (FA) proportions consisting of up to 8% as alternative fillers in modified mixes. The stability values of these filler contents (2, 4, 6, and 8%) were 13.98 kN, 15.44 kN, 19.48 kN, and 17.52 kN with 5.07, 4.9, 4.8, and 5.4 OAC, respectively. When compared to a conventional mix and standard specification, their test results demonstrated a significantly greater stability value with such a relatively low OAC again for mix with 4% FA as the optimum filler content. Ahyudanari et al. [41] used two types of coal fly ash (5.3% by weight of total aggregate) in their study. They found that the stability values were 11.46 kN and 10.37 kN at 5.60% OAC, respectively. Our research supports the findings that using CD as filler in asphalt concrete has greater stability values than minimum standard requirements given in ASTM D1559 (1989) specifications, which exhibit better adhesion between the aggregate and asphalt.

In this study, Marshall stability decreased as the percentage of WPA in the mixture increased, except for 7% WPA containing samples. That is because by adding tiny sawdust ash (SDA) particles in the AC mixture, the aggregate surface texture becomes smooth and silky [38]. As a result, the strength of SDA added samples decreased compared to the control sample. But all the values show a greater value than the minimum requirement for medium traffic (i.e., stability value of 5.34 kN). Bi and Jakarni [42] used wood ash as a partial replacement of conventional filler on wood ash-modified asphalt mixtures. They summarized that by growing the wood ash content material, the stability value decreases.

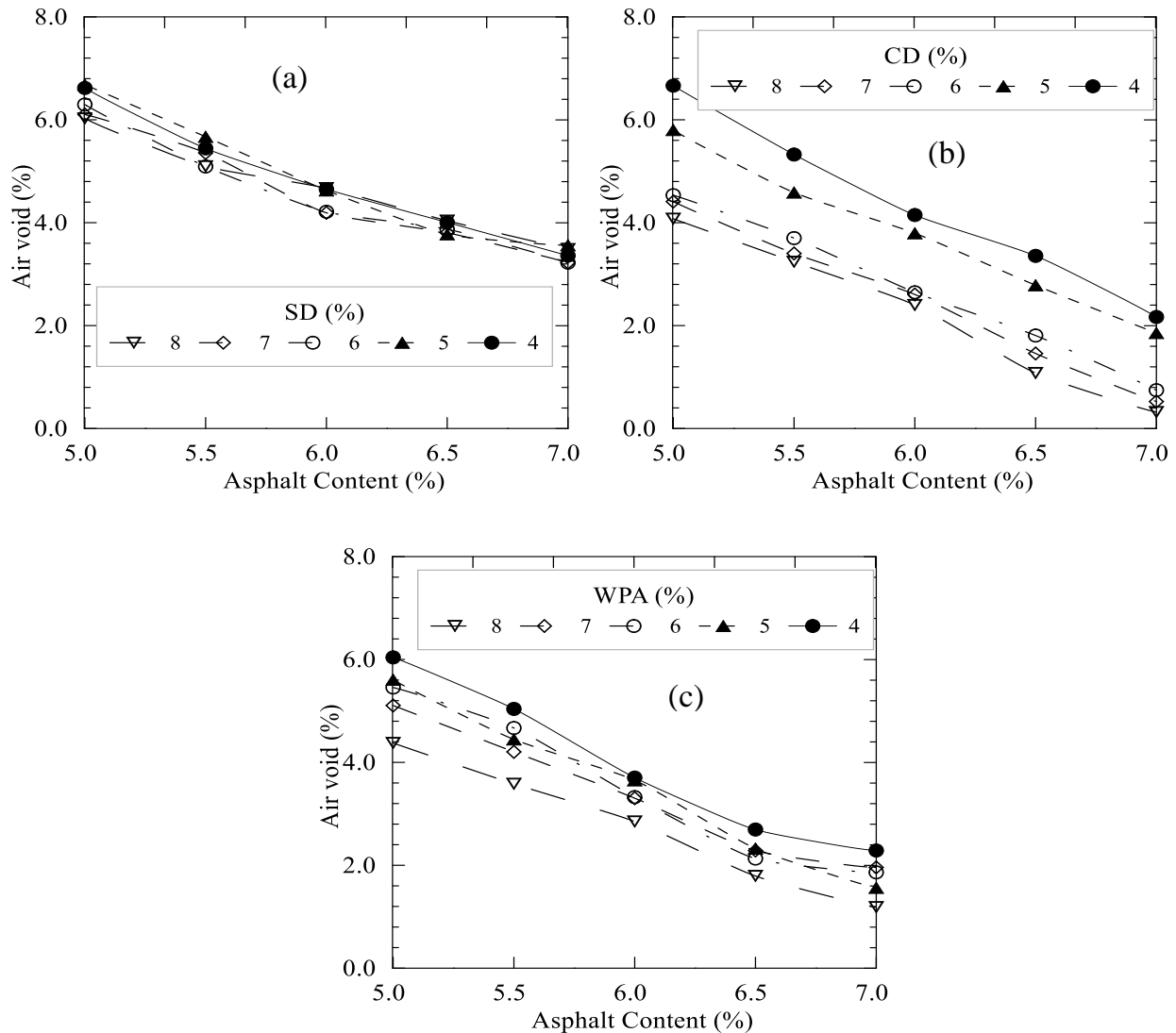


Figure 3. Variation of air void with asphalt content for mixes with different fillers

It is due to fact that wood ash has lesser ductility when compared to conventional fillers. However, most of the stability values are considerably higher than standard requirements.

Figure 4 depicts the voids in mineral aggregate (VMA) percent of the Marshall Specimen at various asphalt content levels for SD (Fig. 4a), CD (Fig. 4b), and WPA (Fig. 4c). Furthermore, as shown in Fig. 4, the VMA values of all specimens decreased for asphalt content percentages up to 5.5%, and then began to increase as the asphalt content percentages increased beyond 5.5%. When a binder is added to a mixture, the aggregate soaks up the binder first, and then the binder fills the void in the mixture. As a result, the VMA value initially declined and then increased because the available void space involves air voids and the effective asphalt content that was not absorbed into the aggregate. Hence, VMA increased as the effective asphalt content increased. The voids in mineral aggregates decline up to a lower limit and then rise as the filler content in the mixes grows [44]. Mistry and Roy [12] used 2, 4, 6 and 8% coal fly ash as fillers, and the VMA% using these filler contents were 15.58, 15.11, 14.78, and 16.16 with 5.07, 4.9, 4.8, and 5.4 % OAC respectively. Durability property is also associated with the VMA value of asphalt concrete combination. The thicker the asphalt film at the combination particles, the more long-lasting the combination [43]. Our test results show a similar trend with the standard trend, and also, all the values are within the specified limits. It is important to note that a minimum VMA value must be maintained to ensure a long-lasting asphalt film thickness.

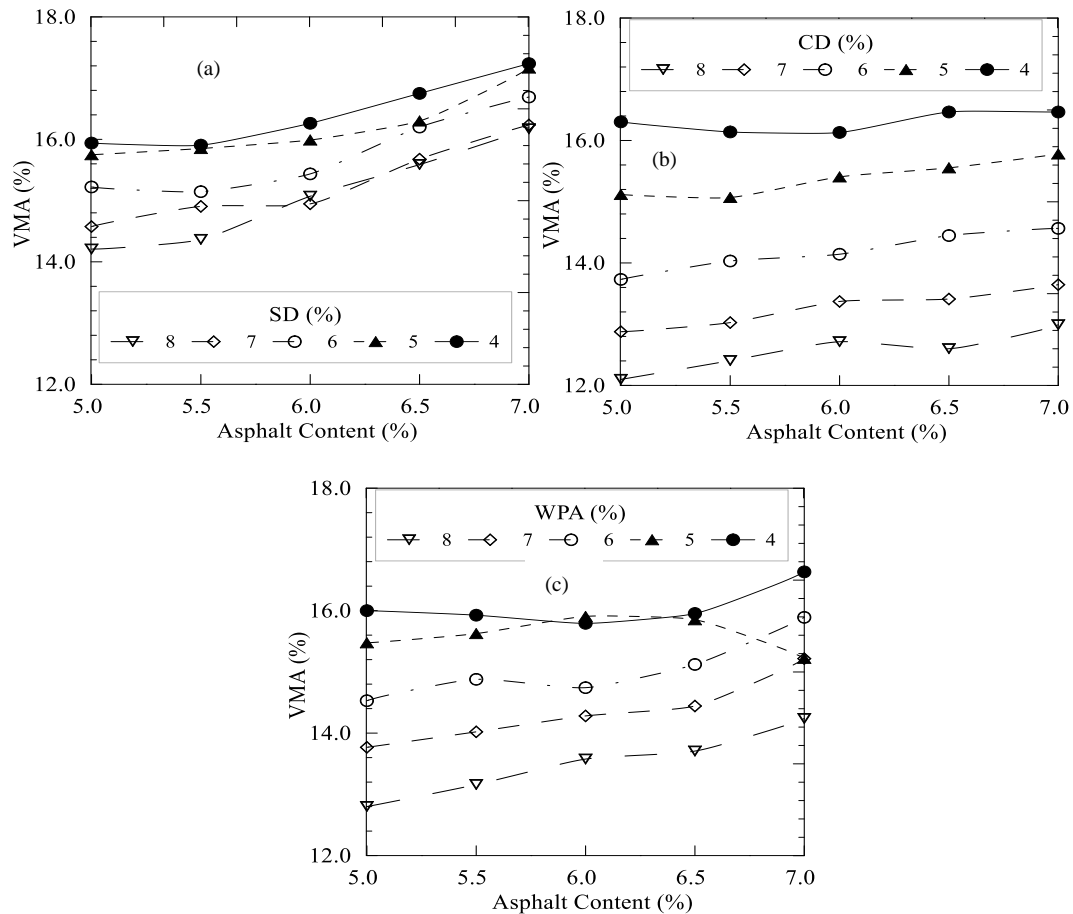


Figure 4. Variation of voids in mineral aggregate with asphalt content for mixes with different fillers

3.2. Determining the optimum asphalt content

The optimum asphalt content (OAC) for Marshall mix is determined by averaging the asphalt contents at (i) highest stability, (ii) highest density, and (iii) maintaining a 4% air void.

Based on Fig. 1 to Fig. 3, the OAC for SD, CD, and WPA mixtures have been calculated and shown in Table 7. The OAC decreased as the filler content increased (Fig. 5a). This is because addition of filler content in the mixture fills the gaps in the aggregate, significantly lowering the gaps in the mineral aggregate and thus leaving less space for asphalt [14, 39, 45].

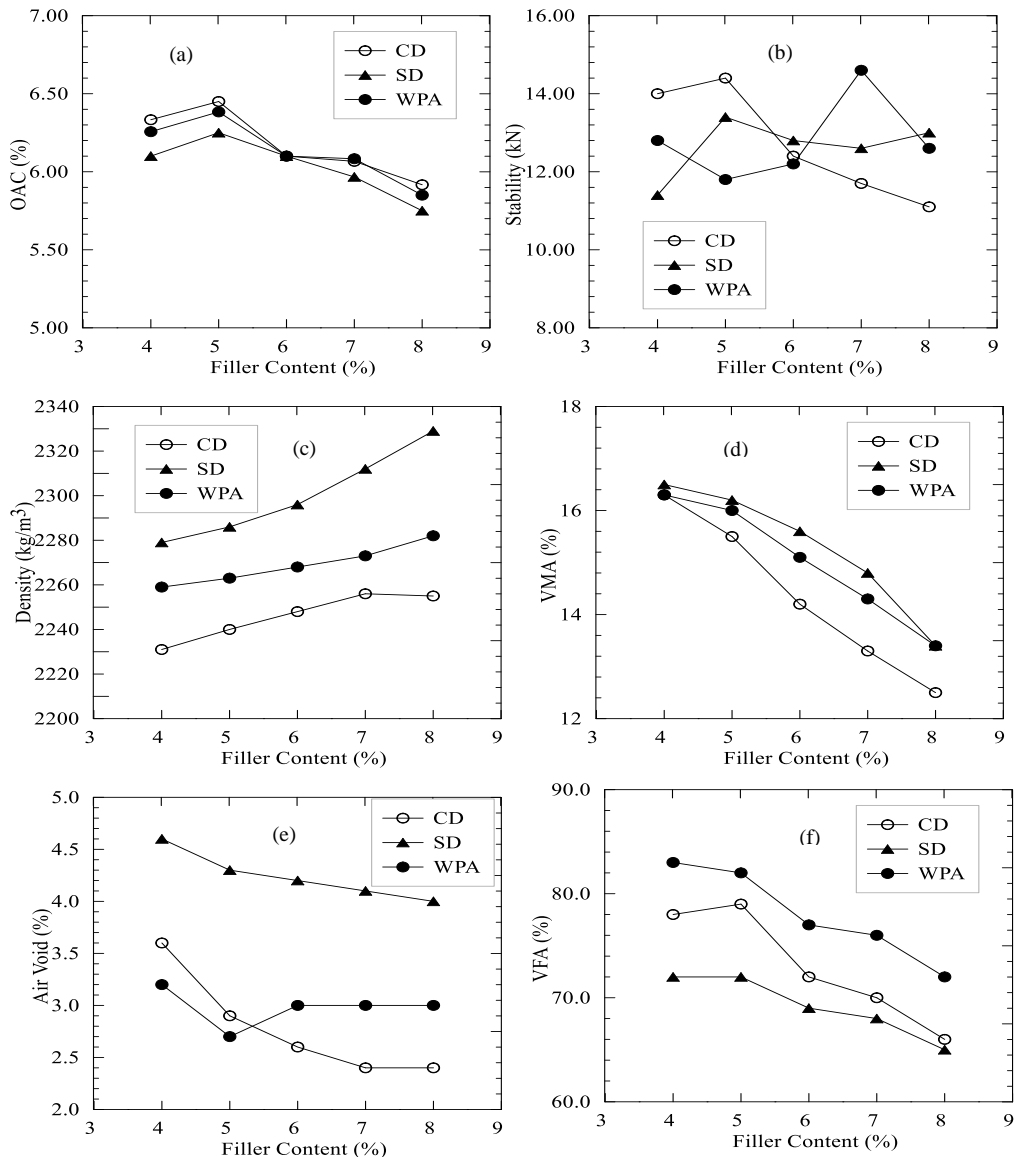
Table 7. OAC for the samples containing SD, CD, and WPA

Filler (%)	Asphalt content with respect to			
	Stability (A_1)	4% air void (A_2)	Maximum density (A_3)	OAC = $(A_1+A_2+A_3)/3$
SD				
4	5	6.5	6.3	6.1
5	6.1	6.45	6.2	6.25
6	6.1	6.2	6	6.1
7	5.85	6.05	6	5.97
8	5.5	5.75	6	5.75
CD				
4	5.9	6.1	7	6.33
5	6.5	5.85	7	6.45
6	6	5.3	7	6.1

Asphalt content with respect to				
Filler (%)	Stability (A ₁)	4% air void (A ₂)	Maximum density (A ₃)	OAC = (A ₁ +A ₂ +A ₃)/3
7	6	5.2	7	6.07
8	5.7	5.05	7	5.92
WPA				
4	6.2	5.87	6.7	6.26
5	6.4	5.75	7	6.38
6	6.15	5.65	6.5	6.1
7	6.2	5.55	6.5	6.08
8	5.8	5.25	65	5.85

3.3. Marshall properties concerning optimum asphalt content

This Table 8 illustrates the Marshall properties of the mixes (prepared with CD, WPA, and SD) with respect to the OAC and the graphical representation of the relationships between filler contents with OAC, stability, density, VMA%, air void%, VFA%, flow value, effective asphalt content (Pbe) and retained stability (RS) values are shown in Fig. 5 (a), 5(b), 5(c), 5(d), 5(e), 5(f), 5(g), 5(h) and 5(i), respectively.



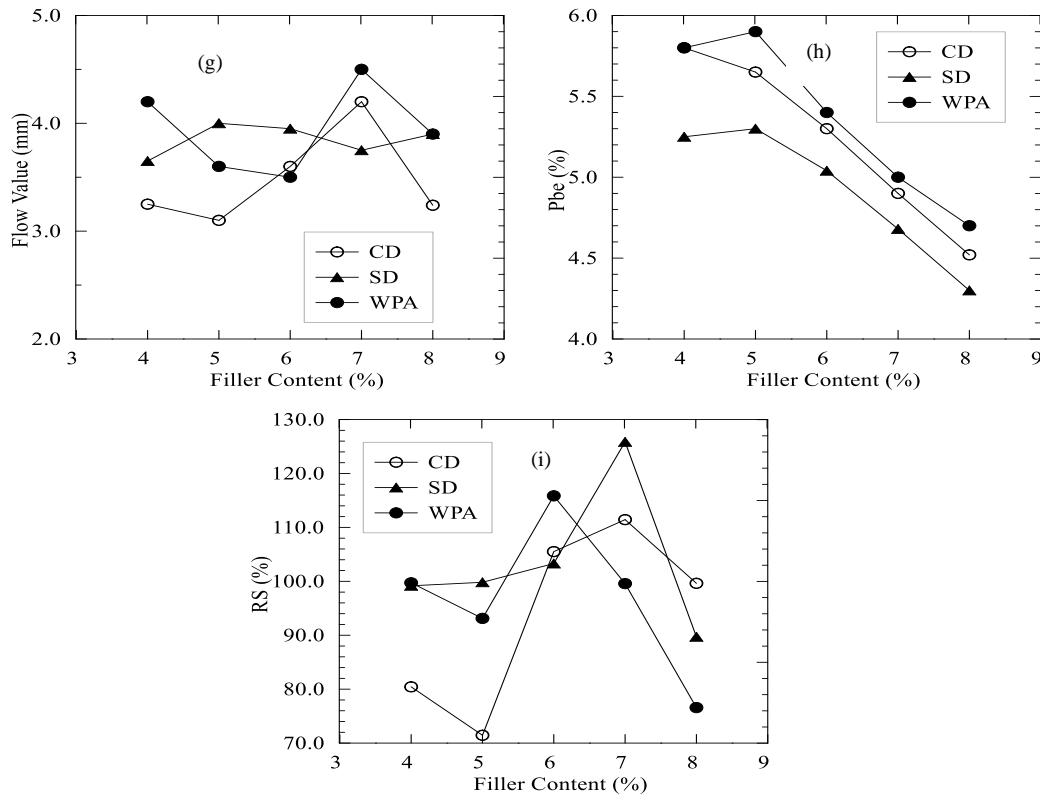


Figure 5. Marshall Properties with respect to the optimum asphalt content (OAC) at various filler contents

For the case of OAC, it was observed that the specimens made with 5%-8% CD filler content satisfied all Marshall criteria except air void (Fig. 5e and Table 8). Exceptionally, specimens made with 4% CD filler content satisfied the all-Marshall criteria including air void and exhibiting a significant stability value (14 kN). Moreover, retained stability (RS) value was within the specified limit (greater than 70%, Table 8). So, it can be concluded that the mixes containing 4% CD can be effectively used.

The specimens made with 4%, 5%, and 7% WPA filler content fulfilled the requirements of all Marshall properties except either VFA, flow value or both (Table 8, Fig. 5f, Fig. 5g), however the differences were not significant. Nevertheless, the specimens with 6% and 8% WPA filler contents satisfied all Marshall criteria including stability values (11.2 kN and 12.6 kN, respectively), and those percentages of WPA filler content can be effectively used in the asphalt concrete mixes. In comparing 6% and 8% filler content mixtures, it may be better to use 6% filler content than 8% as the effective asphalt content (Pbe) values are higher at 6% and also require less filler materials (Fig. 5h and Table 8). It is significant to mention that the conventional SD filler does not require any filler content percentage (Table 8) to satisfy the Marshall criteria but the studied CD and WPA require a certain filler content percentage to satisfy the Marshall criteria.

Table 8. Marshall Properties with respect to the optimum asphalt

	Standard values	Min ^m 5.34 kN	3-5	13-22	65-78	-	-	2-4	Min ^m 70%
Filler (%)	OAC (%)	Stability (kN)	Air void (%)	VMA (%)	VFA (%)	Density (kg/m ³)	Pbe (%)	Flow (mm)	RS (%)
CD									
4	6.33	14	3.6	16.3	78	2231	5.8	3.25	80.43
5	6.45	14.4	2.9*	15.5	79	2240	5.65	3.1	71.45
6	6.1	12.4	2.6*	14.2	72	2248	5.3	3.6	105.51
7	6.07	11.7	2.4*	13.3	70	2256	4.9	4.2*	111.44
8	5.92	11.1	2.4*	12.5	66	2255	4.52	3.24	99.63
WPA									

	Standard values	Min ^m 5.34 kN	3-5	13-22	65-78	-	-	2-4	Min ^m 70%
Filler (%)	OAC (%)	Stability (kN)	Air void (%)	VMA (%)	VFA (%)	Density (kg/m ³)	Pbe (%)	Flow (mm)	RS (%)
4	6.26	12.8	3.2	16.3	83*	2259	5.8	4.2*	99.72
5	6.38	11.8	2.7*	15.8	82*	2263	5.9	3.6	93.12
6	6.1	11.2	3	14.8	77	2268	5.4	3.5	115.85
7	6.08	14.6	3	14	76	2273	5	4.5*	99.57
8	5.85	12.6	3	13	72	2282	4.7	3.9	76.58
SD									
4	6.1	11.4	4.6	16.5	72	2279	5.25	3.65	99.17
5	6.25	13.4	4.3	16.2	72	2286	5.3	4	99.82
6	6.1	12.8	4.2	15.6	69	2296	5.04	3.95	103.30
7	5.97	12.6	4.1	14.8	68	2312	4.68	3.75	125.86
8	5.75	13	4	13.4	65	2329	4.3	3.9	89.71

Note: * denotes the values which are not within the acceptable limits.

4. Conclusions

The use of waste products as non-conventional fillers in asphalt concrete mix enhances pavement performance and also contributes to a sustainable waste management system. In this research, an effort has been made to check the feasibility of using coal dust (CD) and wood powder ash (WPA) as alternative filler materials through evaluating deformation resistance or stability, fatigue resistance, durability properties of CD and WPA containing asphalt concrete with the help of Marshall properties (i.e., stability, density, air void, VMA, and VFA). Simultaneously, moisture-induced damages of CD and WPA containing asphalt concrete were measured by retained stability (RS) values. In addition, we obtained a relationship between the optimum asphalt content and percentage of mineral filler.

Initially X-ray fluorescence (XRF) observation were conducted to determine the physical and chemical properties of the filler materials (i.e., CD, WPA) and found significant percentages of SiO₂, Al₂O₃, and Fe₂O₃ that indicates the suitability of CD and WPA as mineral filler in asphalt concrete mixes. In the second step, 90 Marshall specimens containing CD, WPA, and SD (control specimen) for medium traffic condition were prepared and tested in the laboratory for Marshall properties with different filler contents (4%, 5%, 6%, 7%, and 8%). Finally, similar Marshall specimens were prepared and tested for optimum asphalt content at different filler contents. For medium traffic conditions, the stability values of Marshall specimens containing CD, WPA, and SD are much higher than the minimum (i.e., 5.34 kN) load requirement which can provide deformation rigidity when subjected to frequent or sustained load. Among the fillers, SD mixtures exhibited more dense and VMA percentage than WPA and CD. However, the differences in the results were not significant and VMA values of CD and WPA mixtures were less than 22 that satisfied the AASHTO criteria. The air void values for the Marshall specimens were within the specified limit.

The OAC is highest for mixes with CD as followed by WPA and SD. Specimens made with 4% CD and 6% WPA filler content satisfied all-Marshall criteria along with considerable stability and retained stability value. Though 8% WPA filler content mixtures show similar results as 6% WPA filler content yet the effective asphalt content (Pbe) values are lower at 8% and also require more filler materials. For control mix specimen SD, it does not require any filler content percentage to satisfy the Marshall criteria but CD and WPA necessitate a particular percentage of filler content to satisfy Marshall criteria. Therefore, the study reveals that 4% CD filler content and 6% WPA content can be effectively used as a mineral filler in asphalt concrete mixes.

This study gives a preliminary guidance to use wood powder ash (WPA) and coal dust (CD) as alternate filler materials in asphalt concrete. Further experimental investigation on properties including indirect tensile fatigue test, four-point bending test, repeated axial load test, and wheel tracking test should be performed while using CD and WPA as filler materials on the pavement.

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

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