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CHARACTERIZATION OF BINARY BATCHED CONCRETE CONTAINING SAW DUST ASH FOR ROLLER COMPACTED CONCRETE PAVEMENT APPLICATION

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Abstract: Concrete industry is one of the largest consumers of natural resources due to which sustainability of concrete industry is under threat. The environmental and economic concern is the biggest challenge concrete industry is facing. In this research, the issues of environmental and economic concern were addressed by the use of saw dust ash as partial replacement of Hydraulic cement in roller compacted concrete pavement. Hydraulic cement was replaced by Saw Dust Ash as 10%, 20%, 30% and 40% by weight. The concrete specimens were tested for slump at fresh state, flexural strength at 7 days, and 28 days of age and compressive strength at 3 days, 7 days, 14 days, 28 days, and 56 days of age. The results obtained were compared with the specifications of relevant standard specifications. The research concluded that Saw Dust Ash is a suitable material for partial replacement of hydraulic cement up to 30% by weight at 1: 3.5: 3 mix ratio for standard and high performance roller compacted concrete pavement.
Keywords: Compressive strength, Concrete industry, Flexural strength, Hydraulic cement, Roller compacted concrete pavement, Saw dust ash

1. INTRODUCTION

Roller–compacted concrete (RCC) gets its name from the heavy vibratory steel drum and rubber–tired rollers used to compact it into its final form. RCC has similar strength properties and consists of the same basic ingredients as conventional concrete—well–graded aggregates, cementitious materials, and water—but has different mixture proportions. The largest difference between RCC mixtures and conventional concrete mixtures is that RCC has a higher percentage of fine aggregates, which allows for tight packing and consolidation. Fresh RCC is stiffer than typical zero–slump conventional concrete. Its consistency is stiff enough to remain stable under vibratory rollers, yet wet enough to permit adequate mixing and distribution of paste without segregation (PCA MC043, 2002, PCA EB215.02, 2002, PCA IS009, 2004, PCA IS328, 2005).

RCC is typically placed with an asphalt–type paver equipped with a standard or high–density screed, followed by a combination of passes with rollers for compaction. Final compaction is generally achieved within one hour of mixing. Unlike conventional concrete pavements, RCC pavements are constructed without forms, dowels, or reinforcing steel. Joint sawing is not required, but when sawing is specified, transverse joints are spaced farther apart than with conventional concrete pavements (PCA MC043, 2002, PCA EB215.02, 2002, PCA IS009, 2004, PCA IS328, 2005, PCA, 2007a, PCA, 2007b, U.S. Army Corps of Engineers, 2000).

RCC pavements are strong, dense, and durable. These characteristics, combined with construction speed and economy, make RCC pavements an excellent alternative for parking and storage areas; port, intermodal, and military facilities; highway shoulders; streets; and highways. RCC can also be used in composite systems as base material (PCA MC043, 2002, PCA EB215.02, 2002, PCA IS009, 2004, PCA IS328, 2005, PCA, 2007a, PCA, 2007b, U.S. Army Corps of Engineers, 2000). The use of RCC in public and private applications has been increasing steadily in recent years particularly in the construction of low–volume roads and parking lots (Pittman and Anderton 2009, Harrington, et al 2010, and U.S. Army Corps of Engineers, 2000).

RCC mixtures can be made with any of the basic types of hydraulic cement, blended cements, or a combination of hydraulic cement and pozzolan. A detailed discussion of the selection and use of hydraulic cements and supplementary cementitious materials can be found in ACI 225R, Guide to the Selection and Use of Hydraulic Cements, and Integrated Materials and Construction Practices for Concrete Pavement: A State–of–the–Practice Manual (IMCP 2007/FHWA HIF–07–004 (2007)). As with conventional concrete, materials used in RCC mixtures should be selected for chemical resistance to sulfate attack, potential alkali reactivity, and resistance to abrasion. The type of cementitious material used has a significant effect on the rate of hydration and the rate of strength development and, therefore, significantly affects strength at early ages.

Sumaila and Job (1999), assessed the properties of cement –saw dust ash concrete at percentage replacement of cement with saw dust ash of 0 to 30% and reported that all the tested samples developed over 60% of their 28–day strength at 7 days. They recommended the use of saw dust ash to partially replace cement up to a maximum percentage replacement of 5–10% by volume. Udoeyo and Dashibil (2002) found that saw dust ash concrete at 10% replacement of cement with saw dust ash attained the same strength level with conventional concrete (0% replacement) at longer curing ages. Saw Dust Ash (SDA) satisfies the requirement of combined SiO2, Fe2O3 and Al2O3 of more than 70% which makes it a good pozzolan (Raheem, and Sulaiman, 2013).

The primary objective of this research is to evaluate the suitability Saw Dust Ash as Partial Replacement of Hydraulic Cement in Roller Compacted Concrete Pavement. Saw dust is waste material produced from timber industry. The saw dust ash can be used as a supplementary cementitious materials (SCM) considering its pozzolan and cementing properties. It can also provide additional fine material and ensure adequate compaction, particularly in mixtures containing standard graded concrete fine aggregate. The use of saw dust ash as supplementary cementitious material reduces the cost of cement and lead to cost effective construction.

2. MATERIALS

— Cementitious materials

As with conventional concrete, materials used in RCC mixtures should be selected for chemical resistance to sulfate attack, potential alkali reactivity, and resistance to abrasion. The type of cementitious material used has a significant effect on the rate of hydration and the rate of strength development and, therefore, significantly affects strength at early ages. Type I and II cements are commonly used in RCC pavements. Type III can be used when early strength gain is required, and Type V can be used in areas that have specific soil conditions calling for this type of cement. Cementitious materials should meet the requirements of ASTM C150 or ASTM C1157.

Supplementary cementitious materials (SCM) can also be used to provide additional fine material and ensure adequate compaction, particularly in mixtures containing standard graded concrete fine aggregate. SCMs may improve workability, reduce the potential for alkali aggregate reaction and alkali–silica reactivity, extend the compaction time, and—in the case of silica fume—help in freeze–thaw conditions. The hydraulic cement and saw dust ash used in this study complied with the specifications of ASTM C150/C150M–17 (2017), ACI 225R (2016), ASTM C618–15, (2015), and FHWA HIF–07–004 (2007). Table 1 shows the properties of the saw dust ash used in this study.

Table 1: Properties of saw dust ash

Oxides	Percentage composition (%)
SiO_2	65.30
Al_2O_3	4.0
Fe_2O_3	2.23
CaO	9.6
MgO	5.8
MnO	0.01
NaO	0.07
K_2O	0.11
P_2O_5	0.43
SO_2	0.45
LOI	2.11

— Fine aggregate

Fine aggregate used in this study met the specifications and durability requirements specified in ASTM C33/C33M–16e1 (2016) and AASHTO M6–03 (2013). The selection of fine aggregates is crucial because it determines the water requirement (and hence the cement consumption), surface smoothness, and durability of the RCC. River sand is a good source of concrete sand; however, manufactured sand is also widely accepted and used in RCC production. Screening (PCA MC043, 2002, PCA EB215.02, 2002, PCA IS009, 2004, PCA IS328, 2005, PCA, 2007a, PCA, 2007b, U.S. Army Corps of Engineers, 2000).

— Coarse aggregate

The coarse aggregates used in this study conforms to the specifications of ASTM C33 /C33M – 16e1 (2016) and AASHTO M80–87 (2013). Coarse aggregates were limited to nominal maximum size aggregate (NMSA) of 3/4 in. (19 mm) to prevent segregation and achieve a tight surface.

— **Water**

The water available for chemical hydration within RCC comes from two sources. A portion is contained as excess (free) water in the fine and course aggregates, and the balance of the required water is added at the mixing plant (PCA MC043, 2002, PCA EB215.02, 2002, PCA IS009, 2004, U.S. Army Corps of Engineers, 2000). Water used in mixing and curing concrete specimens in this study met the quality requirements specified in ASTM C1602 / C1602M–12, (2012).

3. METHODS

— **Aggregate properties**

Aggregates used in conventional concrete with a good proven record should also perform well in RCC. As with conventional concrete, the aggregate source should be inspected and tested for quality and consistency throughout the construction period. Testing can be performed to confirm the consistency of the aggregate gradation as well as properties such as absorption, specific gravity, plasticity index, abrasion resistance, alkali–silica reactivity (ASR), and durability.

The sieve analysis, specific gravity, water absorption of the fine and coarse aggregate were conducted in accordance with FHWA HIF–07–004 (2007), ASTM C33/C33M–16EI (2016), AASHTO T84 (2013) and AASHTO T85 (2013) respectively. The aggregate crushing value and the Los–Angeles abrasion value tests were conducted for the coarse aggregate in accordance with ASTM C33/C33M – 16el (2016) , ASTM C131/C131M (2014), PCA IS328, (2005), PCA (2007a), PCA, (2007b), U.S. Army Corps of Engineers, (2000).

— **Concrete mix design and slump test**

As with the selection of materials, the correct proportioning of the materials is critical to the production of quality RCC mixtures. The mixture design process should not use a trial and–error approach, but rather a scientific and systematic approach that takes into account the desired engineering properties, construction requirements, and economics. The concrete mixes were designed and batched in accordance with the specifications of ACI 325, (2004), PCA MC043, (2002), PCA EB215.02, (2002), PCA IS009, (2004). The water cement ratio was maintained at 0.4 and the maximum size of coarse aggregate used ranges from 16mm to 19mm. The slump test was carried out to determine the consistency of the fresh concrete and it is in conformance with FHWA HIF – 07 – 004 (2007).

— **Compressive strength and flexural strength**

To accommodate materials variability and variability during actual mixing, transportation, and construction, RCC mixes should be proportioned in the laboratory to achieve strengths higher than the specified strengths (Harrington et–al 2010, and Pittman and Anderton 2009). The concrete specimens were of 150mm diameter and 300mm long for both compressive strength and split tensile strength analysis. The compressive strength of the specimens was evaluated at the 3rd, 7th, 14th, 28th, and 56th day age in accordance with the specifications of U.S. Army Corps of Engineers, (2000), PCA IS009, (2004), PCA EB215.02, (2002), PCA IS328, (2005), ACI 214R–11, (2011), and FHWA HIF – 07 – 004 (2007). The split tensile test was evaluated using the third point loading.

— **Water absorption and Voids in hardened concrete:**

The density, percentage absorption, and percentage voids in hardened concrete for different percentage replacement of NCA with CBA was determined in accordance with the procedure specified in ASTM C642 (2013) and NCPTC (2008) at the 28th day of curing. The specimens used were 100mm diameter and 50mm thick cylindrical concrete of volume 393cm^3 and oven dry mass of 943g. Each portion of the specimens were free from observable cracks, fissures, or shattered edges.

4. RESULTS & DISCUSSION

— **Aggregate properties**

Well graded fine and coarse aggregates were used in this study to optimize the aggregates from the perspectives of gradation, segregation resistance, and compatibility. The aggregates satisfied the specifications of ASTM C33/C33M–16e1 (2016), PCA IS328, (2005), PCA (2007a), PCA, (2007b), U.S. Army Corps of Engineers, (2000). Table 2 shows the aggregate properties.

Table 2: Aggregate properties.

Aggregate	Specific gravity	Water absorption (%)	Aggregate crushing value (%)	Aggregate impact value (%)	Los Angeles abrasion value (%)
Fine	2.633	1.434	–	–	–
Coarse	2.731	1.23	19.63	22.54	24.71

— **Concrete mix ratio**

As with the selection of materials, the correct proportioning of the materials is critical to the production of quality RCC mixtures. The mixture design process should not use a trial and–error approach, but rather a scientific and systematic approach that takes into account the desired engineering properties, construction requirements, and economics (Harrington et al, 2010, Pittman, D.W. and G.L. Anderton, 2009, and PCA, 2007b).

From Table 3, it can be observed that hydraulic cement content is 320Kg/m^3, the fine aggregate to total aggregate ratio is 0.5385 and the coarse aggregate to total aggregate ratio is 0.4615. This satisfies the minimum cementitious content of 300Kg/m^{3}to 360Kg/m^3 for concrete pavement, the fine aggregate to total aggregate ratio specifications of 0.50 to 0.55 and the coarse aggregate to total aggregate ratio of 0.45 to 0.5 for roller compacted concrete pavement specified in U.S. Army Corps of Engineers, (2000), PCA (2007b), PCA IS328, (2005), PCA IS009 (2004), PCA EB215.02 (2002), and ACI 325, (2004).

Table 3: Concrete mix ratio 1: 3.5:3

Specimen mark	Percentage replacement of cement with saw dust ash (%)	Water–Cementitious material ratio	Cementitious material (kg/m^3)		Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
			Cement	Saw dust		
SDA–C1	0	0.4	320	0	1120	960
SDA–C2	10	0.4	288	32	1120	960
SDA–C3	20	0.4	256	64	1120	960
SDA–C4	30	0.4	224	96	1120	960

— **Compressive strength and flexural strength of roller compacted concrete**

According to U.S. Army Corps of Engineers, (2000), PCA (2007b), PCA IS328, (2005), PCA IS009 (2004), PCA EB215.02 (2002), ACI 325, (2004), ACI 214R–11 (2011), and ACI 121R–08 (2008) the compressive strength of RCC is comparable to that of conventional concrete, typically ranging from 4,000 to 6,000 psi (28 to 41 MPa). To accommodate materials variability and variability during actual mixing, transportation, and construction, RCC mixes should be proportioned in the laboratory to achieve strengths higher than the specified strengths. The target strength is called the required average strength (f'cr).

Tables 4 and 5 show the compressive strength and flexural strength tests results. From Table 4 and Figures 1 and 2 it can be observed that up to 30% replacement of hydraulic cement with saw dust ash satisfied the U.S. Army Corps of Engineers, (2000), PCA (2007b), PCA IS328, (2005), PCA IS009 (2004), PCA EB215.02 (2002), ACI 325, (2004), ACI 214R–11 (2011), and ACI 121R–08 (2008) minimum 28 days compressive strength of 31N/mm^2 to 41N/mm^2 for standard roller compacted concrete pavement and up to 20% replacement satisfied the minimum 28 days compressive strength of 35N/mm^2 to 41N/mm^2 for high performance and high strength roller compacted concrete pavement respectively.

The slump values decreases with increase in percentage of saw dust ash and they and within the range of 3.00mm to 6.00mm. This satisfied the U.S. Army Corps of Engineers, (2000), PCA (2007b), PCA IS328, (2005), PCA IS009 (2004), PCA EB215.02 (2002), ACI 325, (2004), ACI 214R–11 (2011), and ACI 121R–08 (2008) definition of 0.00mm to 6.25mm for zero slump concrete which roller compacted concrete belongs to. The flexural strength results shown in Table 5 satisfied the minimum 28 days flexural strength of 3.5N/mm^2 to 7.00N/mm^2. The 28 days flexural to compressive strength are 13.52, 13.03, 12.49, and 12.12 for 0%, 10%, 20% and 30% replacement of hydraulic cement with saw dust ash. These ratios satisfied the minimum 28 days flexural to compressive strength ratio of 11.39 to 12.9. From Figure 2 it can be observed that the concrete specimens gain have almost the same strength at 56 days age.

Table 4: Slump and compressive strength test results

Specimen mark	Percentage replacement of cement with saw dust ash (%)	Slump (mm)	Compressive strength (N/mm^2)				
			3 days	7 days	14 days	28 days	56 days
SDA–C1	0	6.0	16.44	21.33	33.65	40.24	47.38
SDA–C2	10	5.5	14.13	19.22	31.45	38.22	47.00
SDA–C3	20	4.0	12.24	15.35	27.22	35.31	45.87
SDA–C4	30	3.0	11.31	14.22	24.56	33.53	42.21

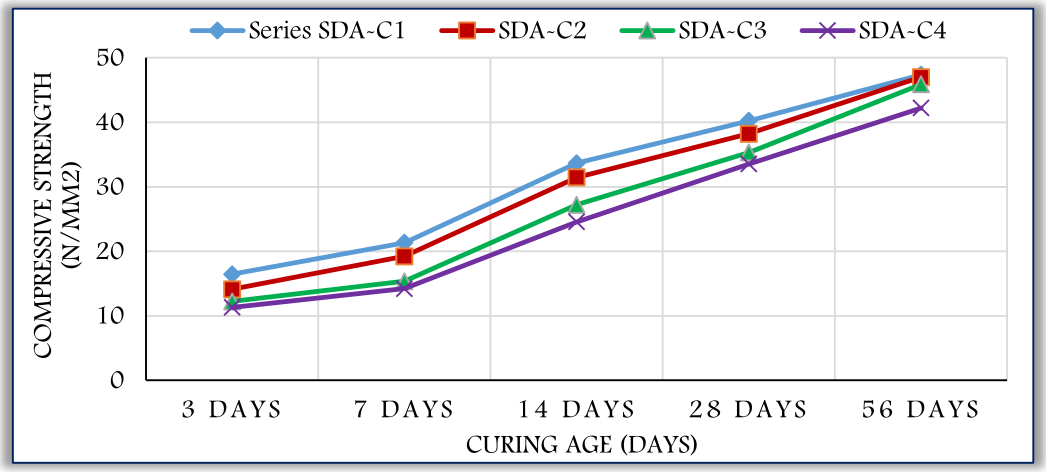

Figure 1. Relationship between compressive strength (N/mm²) and Curing age (days)

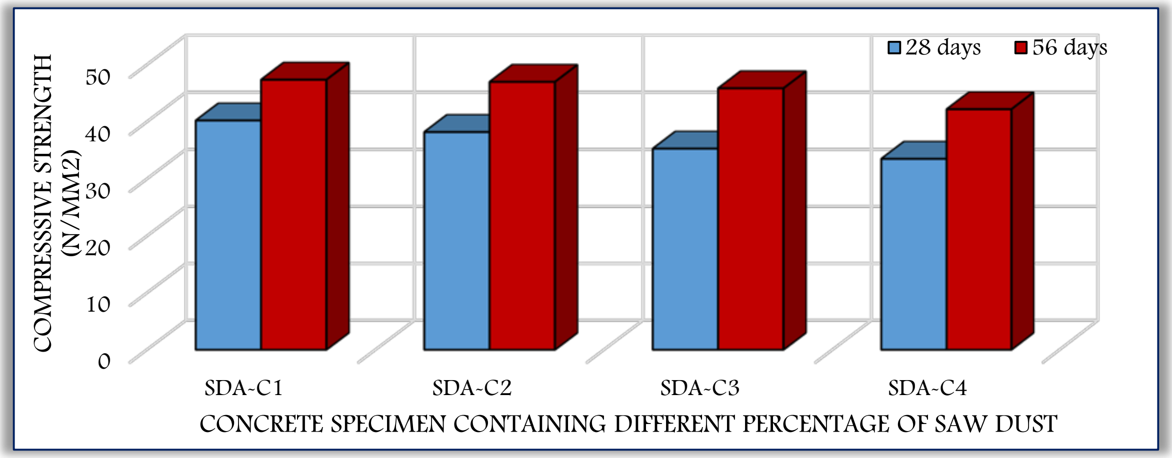

Figure 2. The 28 days and 56 days compressive strength of concrete specimens containing different percentage of saw dust ash

Table 5. Split tensile and flexural strength

Specimen mark	Split tensile strength (N/mm²)		Flexural strength (N/mm²)	
	7 days	28days	7 days	28 days
SDA–C1	3.97	5.44	4.84	6.21
SDA–C2	3.64	5.32	4.61	6.01
SDA–C3	3.42	4.89	4.21	5.89
SDA–C4	3.23	4.44	3.87	5.43

— **Water absorption and Voids in hardened concrete:**

The specimen use for the Water absorption and Volume of permeable pore space (voids) in hardened concrete at 28thday age satisfied the specifications of ASTM C642 (2013) and NCPTC (2008). From Table6 and Figure 3 it can be observed that water absorption after immersion, water absorption after immersion and boiling and volume of permeable pore space (voids) decrease with increase in percentage replacement of cement with saw dust ash. This indicates that the saw dust ash concrete has reliable durability qualities and will perform favorably if used in roller compacted concrete pavement.

Permeability is defined as the ease with which fluids can penetrate concrete. Permeability and water absorption can be lowered by reducing the number of connected pores within the paste system of a mixture. This can be accomplished through a lower water/cement ratio (w/cm), improved curing, and the use of supplementary cementitious materials (SCMs). The boil test measures the volume of permeable pore space in a concrete mixture. Permeability of the concrete in a Portland cement concrete pavement is a major factor for long–term durability. Pavements with low permeability resist penetration of moisture into the concrete matrix, leading to long–term durability.

Table 6: Water absorption and Volume of permeable pore space (voids) in hardened concrete at 28thday age.

S/N	Description and units	Symbols and equations	Percentage replacement of cement with saw dust ash			
			0%	10%	20%	30%
1	Volume of sample (cm^3)	V	393	393	393	393
2	Mass of oven dry sample in air (g)	A	952	955	959	963
3	Mass of surface–dry sample in air after immersion (g)	B	1003	1001	1000	1000
4	Mass of surface–dry sample in air after immersion and boiling (g)	C	1007	1006	1004	1004
5	Apparent mass of sample in water after immersion and boiling (g)	D	614	613	611	611
6	Absorption after immersion (%)	$= \left[\frac{(B-A)}{A}\right] X\ 100$	5.4	4.8	4.3	3.8
7	Absorption after immersion and boiling (%)	$= \left[\frac{(C-A)}{A}\right] X\ 100$	5.8	5.3	4.7	4.2
8	Density of water (g/cm^3)	$\rho = 1$				
9	Bulk density, dry (g/cm^3)	$g1 = \left[\frac{A}{C-D}\right] X\ \rho$	2.42	2.43	2.44	2.45
10	Bulk density after immersion (g/cm^3)	$= \left[\frac{B}{C-D}\right] X\ \rho$	2.55	2.55	2.55	2.55
11	Bulk density after immersion and boiling (g/cm^3)	$= \left[\frac{C}{C-D}\right] X\ \rho$	2.56	2.56	2.56	2.56
12	Apparent density (g/cm^3)	$g2 = \left[\frac{A}{A-D}\right] X\ \rho$	2.82	2.79	2.76	2.74
13	Volume of permeable pore space or voids, (%)	$= \left[\frac{g2-g1}{g2}\right] X\ 100$ Or $= \left[\frac{(C-A)}{(C-D)}\right] X\ 100$	14.18	12.90	11.59	10.58

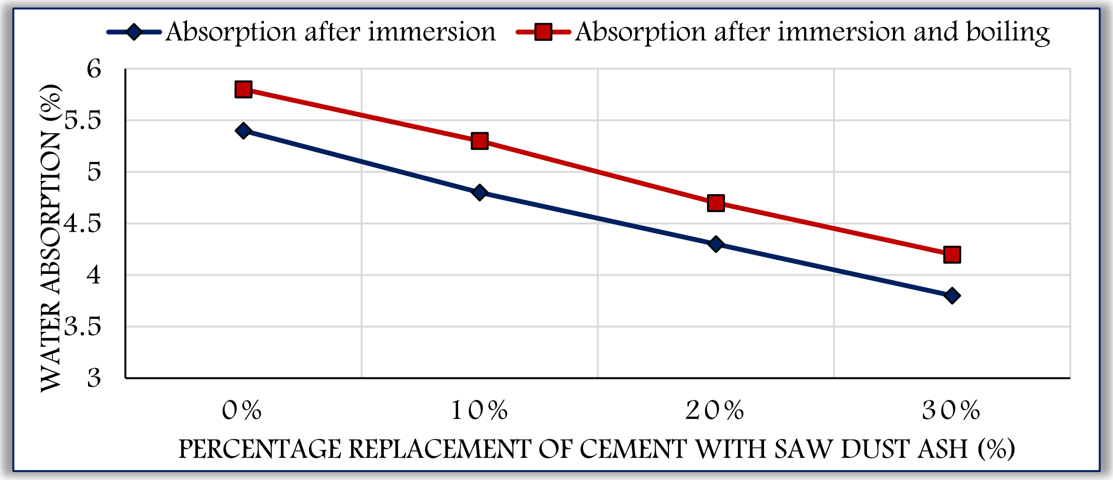

Figure 3: Water absorption after immersion in hardened concrete at 28thday (%)

5. CONCLUSION

At the end of this study, the following conclusions can be drawn:

- Saw dust ash is a suitable material for use as a pozzolan, since it satisfied the requirement for such a material by having a combined ($SiO_2+Al_2O_3+Fe_2O_3$) of more than 70%. Indicating similar properties with Class F fly ash.
- Roller compacted Concrete becomes more workable as the saw dust ash percentage increases meaning that less water is required to make the mixes more workable .This means that saw dust ash roller compacted concrete has lower water demand.

- Compressive strength generally increases with curing period and decreases with increased amount of saw dust ash. Up to 20% substitution satisfied the minimum 28 days compressive strength of 28N/mm² to 41N/mm² specified by U.S. Army Corps of Engineers, (2000), PCA (2007b), PCA IS328, (2005), PCA IS009 (2004), PCA EB215.02 (2002), ACI 325, (2004), ACI 214R–11 (2011), and ACI 121R–08 (2008) .
- Use of saw dust ash in roller compacted concrete pavement leads to cost effective concrete pavement as it is non useful waste and can be obtained free of cost. It will reduce pressure on cement consumption and thus make concrete construction industry sustainable
- Use of saw dust ash in roller compacted concrete will eradicate the disposal problem of saw dust, reduce disposal cost and reduce pressure on the limited landfills.
- Use of saw dust ash in roller compacted concrete pavement leads to environmental friendly construction, thus paving way for green concrete.

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