Proceedings of 8th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2020 Month: June Volume: 8

Strength Optimization of Sawdust Concrete through Cement Variation

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Abstract

The use of concrete in modern world construction dominates material use worldwide. Along with the use, surging popularity has also drawn attention towards concrete composition, component modification, and variation. The research attempts made towards reducing the density of the concrete without significant impact on strength have resulted in the use of various materials from sawdust to sawdust ash, coconut shell, and many more. Many research efforts have endorsed sawdust as the optimal material for the partial replacement of the fine aggregate. These efforts have mainly focused on the variation of the fine aggregate by the sawdust. Despite the attempts, only a few have resulted in significant results in regard to strength, and economical contribution. This paper provides an insight into the possibility of fine aggregates replacement without a prominent decrease in the strength of the concrete. The paper primarily focuses on the determination of optimum content of sawdust incorporating the strength of the concrete, economical aspects, and its environmental impact based on the replacement of sawdust. The paper also attempts to optimize the partially replaced sawdust concrete with the variation of cement. The results from the compressive strength test and tensile strength test show significant improvement in the strength of concrete.

Keywords

Sawdust concrete, Cement Variation, Mechanical Properties, Concrete Materials, Compressive Strength

1. Introduction

Concrete is the second most consumed material in the world after water [1]. The use of concrete in construction has almost replaced all other conventional construction materials (e.g. mud mortar, brick/stone masonry, timber, etc.). The ability of concrete to gain remarkable strength in a short period has surged the popularity of concrete among the construction materials [2, 3] resulting in an all-time high concrete construction [4, 5].

The increase in popularity has also urged researchers to find lightweight alternative construction materials at a lower cost without compromising the strength [6, 7]. The easy availability of sawdust in the tropical region has supported the use of sawdust as one of the leading fine aggregates replacements [7].

The previous experimental studies provide sufficient evidence for the use of sawdust as a suitable partial fine aggregates replacement [7, 8]. The replacement with sawdust both reduces the organic waste produced and the use of sand (as fine aggregates) thereby also reducing the exploitation of sand. [9]. Furthermore, the attempts to reduce the cement content in the concrete modification could also prevent environmental pollution [10].

In the context of Nepal, besides dumping sawdust in landfill sites, its use has been limited to the preparation of briquettes. The open space burning of sawdust leads to elemental emissions of potassium and sodium, the release of heavy metals such as lead and mercury in small quantities, which pollute the environment [11, 12]. As sawdust is readily and cheaply available, its use in concrete might result in a reduced cost of concrete composition. Furthermore, the replacement of fine aggregates by sawdust would also help in reducing the exploitation of natural resources. However, fewer in-depth experiments have been attempted towards its mechanical strength modification. This paper focuses primarily on determining the optimum fine aggregates replacement by sawdust while taking strength and cost into consideration. Furthermore, the paper illustrates the impact of cement content variation on the strength of sawdust concrete.

2. Current Trends and Limitations

The experimental study of the partial and full replacement of fine aggregates by sawdust dates back to the 1980s' [7]. The experimental studies have incorporated the use of sawdust in concrete composition [13, 14, 15] to sawdust concrete block [16], and pavement material modification [17].

The use of sawdust in concrete modification even though dates way back, fewer attempts and studies have been done to modify its mechanical properties. The previous studies indicate that sawdust being an organic waste has a higher water absorption rate in comparison to the normal concrete aggregates [14], which hinders the complete replacement of fine aggregates by sawdust.

However, the past experimental studies show that the partial replacement with sawdust provides significant strength to the concrete composition [7, 13, 15, 16]. The experimental data show comparable strength of sawdust concrete relative to nominal concrete with lower density, and the composition could be used to make non-load bearing partition walls and floor slabs [16].

Despite the prior attempts to use sawdust concrete as a lightweight concrete, no further attempts have been made to enhance its mechanical strength through material variation, composition, or modification. The previous experiments point towards the strength of sawdust concrete within the permissible range despite the decrease in its strength compared to nominal mix [7, 16, 13]. The attempts however, have not made any advancement towards increasing the strength of sawdust concrete composition.

3. Scope of the Research

The main scope of the paper is the utilization of sawdust waste in the conventional concrete mixture composition. The paper focuses on finding the optimum sawdust content (partial replacement of fine aggregates) incorporating both structural and economical aspects. Furthermore, the paper studies the mechanical behavior of the concrete with the variation of the cement in the optimized sawdust concrete. Besides, the paper computes the cost analysis of the cement varied sawdust concrete relative to the nominal concrete composition illustrating the cost comparison.

4. Methodology

A standard M20 grade cement concrete mixture was prepared as per Indian Standard Code [18]. The concrete mix process involved dry mixing of cement, fine aggregates and coarse aggregates, followed by wet mixing with water, vibratory compaction of the prepared concrete mix in IS mold, wet curing under controlled conditions and testing of specimen [18]. The prepared cube samples were tested in a standard compressive strength testing machine (Figure 1) for measuring the compressive strength [18]. The standard procedure of strength computation of concrete specimen [18] was followed during fine aggregates replacement by sawdust in the nominal mix and also during variation of cement content in optimum sawdust concrete . Overall, the work was conducted in two phases:

The first phase of work involved determining the optimum fine aggregates replacement (sawdust) in a nominal M20 concrete mix. A nominal mix design for M20 grade concrete was done by adopting Indian Standard (IS) method [19]. The mix proportion obtained is presented in Table 1.

Table 1: Nominal Mix Ratio for M20 grade concrete as per IS Method

Materials	Cement	Fine aggregates	Coarse aggregates	Water
Mass(Kg)	383.2	575.1	980	191.6
Mix Ratio	1	1.501	2.557	0.5

The following materials were collected for the preparation of concrete specimens.

Cement

A 43 grade cement was used throughout the course of work. The specific gravity of the cement was about 3.15.

Coarse aggregates

The coarse aggregates were washed with laboratory water and air-dried. The observed physical and mechanical properties [average of 3 sets of data] are tabulated below:

Fine aggregates and Sawdust

Figure 1: Compression Strength Testing Machine

Figure 2: Arrangement for Sieve Analysis of Sawdust

Figure 3: Treatment of Sawdust

Table 2: Properties of Coarse aggregates

S.N.	Properties	Values
1	Fineness Modulus	6.04
2	Size of aggregates	20mm - 26.5mm
3	Aggregates Crushing Value	23.58 %
4	Density	1650 Kg/m^3

Sawdust *(Shorea Robusta)* was taken from a local mill factory located in Bal Kumari, Lalitpur. Sieve analysis was performed on thus obtained sawdust to conform to the size range of fine aggregates (Figure 2).

Plant fibers tend to have high amounts of sugar as well as other substances such as phenols and acids, which may delay and, in some cases, prevent cement hardening time [15]. To overcome the aforementioned impact, the sawdust was treated with aluminum sulfate (5% proportion weight / weight) for a week (Figure 3). Then after, the treated sawdust was washed with laboratory water and air dried [15].

The fine aggregates were washed and air-dried in the laboratory, similar to the coarse aggregates. The physical and mechanical properties of the fine aggregates and sawdust are presented below :

Table 3: Properties of Fine aggregates and Sawdust

S.N.	Properties	Fine aggregates	Sawdust
1	Fineness Modulus	5.08	5.13
2	Average Size	1.18 mm - 0.6mm	1.18 mm- 0.6mm

Concrete specimens were then prepared with partial replacement of fine aggregates by sawdust in the nominal mix. Since the previous studies have shown better strength results at lower levels whereas a significant decrease in concrete strength at higher replacement levels of fine aggregates replacement, a lower range of 0 to 10% partial fine aggregates replacement was adopted. Thus, the fine aggregates replacement levels of 2.0%, 3.0%, 3.5%, 4.0%, 4.5%, 5.0%, 5.5%, 6.0%, 6.5%, 7.0%, 8.0% and 10.0% by mass (with sawdust) were selected. The 2.0% fine aggregate replacement suggests 98% of fine aggregates and 2% of sawdust amounting to the total weight of fine aggregates (100%) in the nominal mix.

A set of three standard concrete cubes (150mm x 150mm x 150mm) [18] were prepared for each replacement levels and cured for 28-days. After 28-days of wet curing, compression load at failure of all the samples was measured, and their corresponding compressive strengths were computed. The sample with the optimum compressive strength was selected for the second phase of work.

The second phase involved variation in cement content in the concrete mix with optimum fine aggregates replacement by sawdust as obtained from the first phase of work. The cement content was varied in such a way that the total mass of the concrete mix before and after the cement variation was constant. The variations of cement content were -10%(decrease), -5%(decrease), -2.5%(decrease), 0%(no change), +2.5%(increase) and +5.0%(increase) germane to that in optimized concrete mix from first phase of work. For a given mix with a certain cement variation, a set of three-cube and three-cylinder samples [20] each was prepared and cured for 28-days. Thus, a total of 36 cubes and 36 cylinders test specimens were prepared for testing. A set of three samples, each of cubes and cylinders, would be then tested for compressive strength [18] and splitting tensile strength [20] respectively, after 7-days and 28-days curing as shown in Figure 4 and Figure 5. The strengths of samples with different mix proportions were measured and computed. Also, a cost comparison was worked out so that a concrete mix with appropriate cement content was selected for best strength and optimum cost.

Figure 4: Tested Cube and Cylinder Specimens

Figure 5: Cylinder Specimen at Failure Load

5. Results and Analysis

The result of sieve analysis of both fine aggregates and sawdust has been presented graphically in Figure 6.

The compression load at failure of cubes during the first phase of work was noted, and the results of compressive strengths thus obtained are presented in tabular form in Table 4 and graphically in Figure 7.

A mix with 4.5% replacement was selected for the second phase of work based on strength, cost, and environmental consideration.

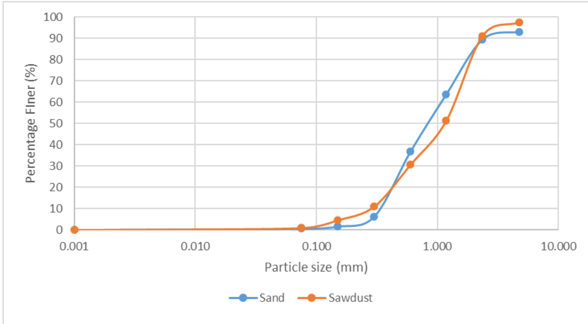

Figure 6: Particle Size Distribution(PSD) Curve

Table 4: Compressive Strength of Specimen with Varying Sawdust Content

Mix Number	Percentage Replacement	28-days strength	
		Load(KN)	Strength(N/mm^2)
0	0	600	26.667
1	2	550	24.444
2	3	421	18.711
3	3.5	484	21.511
4	4	498	22.133
5	4.5	515	22.889
6	5	426	18.933
7	5.5	425	18.889
8	6	409	18.178
9	6.5	395	17.556
10	7	381	16.933
11	8	347	15.442
12	10	328	14.578

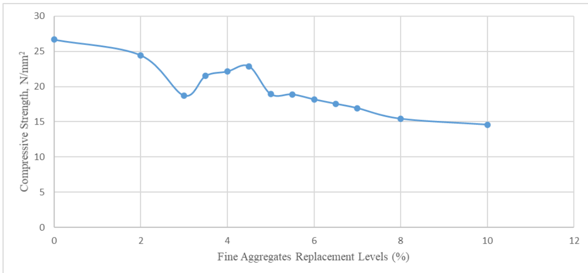

Figure 7: Compressive Strength Variation with Varying Sawdust Content

The compression load at failure of cubes and cylinders prepared during the second phase of work was noted, and the respective compressive strength of cubes [18] and splitting tensile strengths of cylinders [20] were computed. The computed strength results have been tabulated and presented in Table 5. The variations of compressive strength with time for varied cement content have been presented in Figure 8 and that of splitting tensile strength in Figure 9 respectively.

Table 5: Compressive and Splitting Tensile Strengths for Cement Variations

Cement Variation	Compressive Strength (N/mm^2)		Tensile Strength (N/mm^2)	
	7 days	28 days	7 days	28 days
-10.00%	21.59	25.19	2.82	4.87
-5.00%	24.05	31.78	2.65	4.64
-2.50%	20.41	29.04	2.55	2.74
0%	20.86	23.39	4.59	5.09
2.50%	21.26	25.56	2.81	4.94
5.00%	19.25	26.22	1.71	4.29

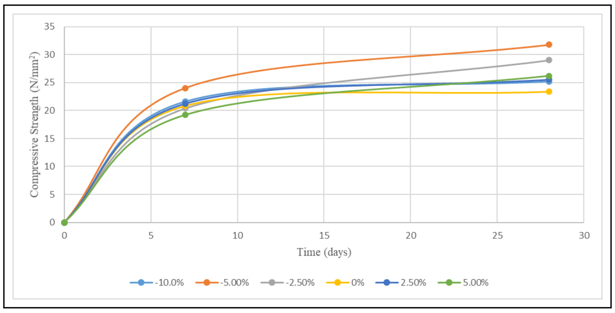

Figure 8: Compressive Strength vs Time for Varying Cement Content

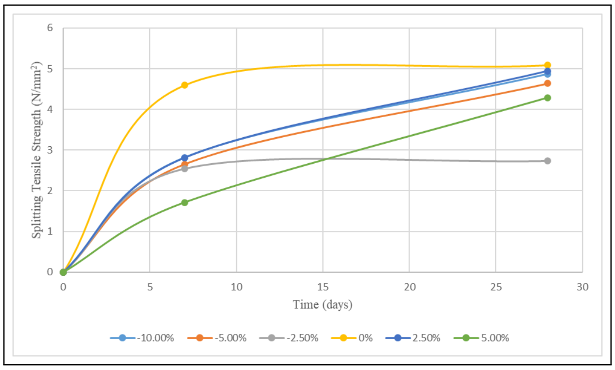

Figure 9: Splitting Tensile Strength vs Time for Varying Cement Content

Furthermore, the cost comparison of samples with different cement replacement levels has also been prepared using "Kathmandu District Rate: 073-74" [21]. The results of cost variation along with compressive strength variations for different concrete mixes have been presented in tabular form in Table 6 and graphically in Figure 10 respectively.

6. Discussion

From sieve analysis and subsequent calculations, the average particle size of sawdust was found to be in the range of 1.18mm - 0.60mm and this range adheres to the size range of fine aggregates required in a concrete

Table 6: Variation of Cost & Compressive Strength for Different Concrete Mix

Concrete Mixture	Fine aggregates Replacement	Cement Variation	Cost (NRs)	Compressive Strength (N/mm^2)
1	0	0	9571	26.667
2	-4.50%	-10.00%	9209	25.185
3	-4.50%	-5.00%	9497	31.778
4	-4.50%	-2.50%	9641	29.037
5	-4.50%	0	9785	23.393
6	-4.50%	+2.5%	9929	25.556
7	-4.50%	+5.00%	10073	26.222

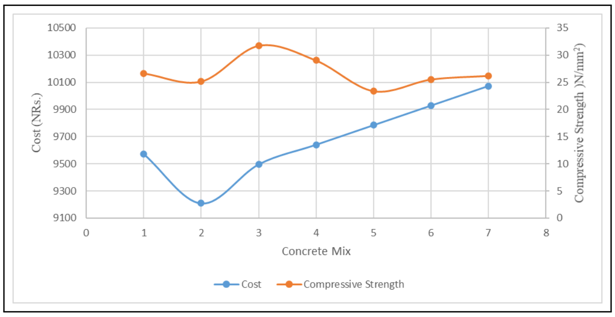

Figure 10: Variation of Cost and Compressive Strength with Concrete Mixture

mix [22]. This justifies the use of sawdust as the replacement of fine aggregates.

The result shown in Figure 7 depicts that the replacement of the fine aggregatet at 4.5% gives the optimum compressive strength relative to the control mix as compared to other replacements. Considering the strength limits, cost, and environmental aspects, fine aggregates replacement at 4.5% (with sawdust) was taken as the optimized replacement level and the second phase of work proceeded with this concrete mix.

Table 5 shows the compressive and splitting tensile strength results at 7-days and 28-days for different concrete mixes. Compressive strength results for 0% variation did not meet the strength standards at the age of 28-days, whereas the rest of the variations met the standards [19]. Figure 8 shows that 7-days and 28-days compressive strength of the concrete mix with -5.00% cement variation depicts satisfactory strength at 24.05 N/mm^2 and 31.78 N/mm^2 respectively. These 28-days strength at -5.00% cement variation correspond to the concrete grade of M25 [19]. The corresponding splitting tensile strength results of 2.65 N/mm^2 at 7-days and 4.64N/mm^2 at 28-days (Figure 9) for -5.00% cement content variation confirm to the Indian Standard [19]. It also verifies the compressive strength results for -5.0%

cement variation. For -5.00% cement variation, there was a rise in splitting tensile strength value at 28-days by 75.1% to that at 7-days. This trend is similar for the increase in cement content beyond 0%, and a decrease in cement content from -5.00%. The increase in the compressive strength of concrete mix with -5.00% cement variation as compared to 0% variation can be explained by the assertion that sawdust in addition to filling up the voids in between the coarse aggregates, also acts as a binder to a lesser extent. That's why, even with the reduction of cement content, the strength of concrete increased substantially. A +10.00% cement content variation concrete mix didn't comply with the workability criteria as it produced a collapse slump.

In Figure 10, the graph shows that the cost of concrete mix 2 (-4.5% fine aggregates replacement, -10% cement variation) and concrete mix 3 (-4.5% fine aggregates replacement, -5% cement variation) is less than that of concrete mix 1 (0% fine aggregates replacement, 0% cement variation). The cost then increased linearly from concrete mix 3 (-4.5% fine aggregates replacement, -5% cement variation) up to concrete mix 7 (-4.5% fine aggregates replacement, +5% cement variation). The strength of concrete mix 3 was highest among all the concrete mixes. Concrete mix 3 with improved strength and low cost compared to the control mix was selected as the best concrete mix for sawdust concrete.

The optimized sawdust concrete (concrete mix 3) with higher strength and reduced cost could be one of the alternative construction materials for use in low-cost masonry construction. When 4.5% of fine aggregate is replaced with sawdust and -5% of cement is varied, this mix also has environmental benefits.

However, the absence of the study of biodeterioration of sawdust concrete, flexural property as well as the interaction of sawdust concrete with steel reinforcement remains the limitations of this paper. Further, the paper deprives the impact of increasing temperature in the sawdust concrete.

7. Conclusion

The use of sawdust as an alternative ingredient for a standard concrete with cement, fine and coarse aggregates was studied. The partial replacement of 2% to 10% fine aggregates by sawdust for concrete of M20 grade showed that the replacement of 4.5% resulted in the optimum strength in the first phase work. With the increase in the replacement amount of fine aggregates by sawdust beyond 6.0%, the strength reduced gradually. Further, cement content variation in the concrete mix with 4.5% fine aggregates replacement was also observed in the detailed phase. The 28-days compressive strength result pointed out that a further 5% reduction of cement content improves the strength of concrete with partial replacement of fine aggregates by sawdust, which is comparable with M25 grade nominal concrete[19]. Moreover, the results indicate that the sawdust does not merely act as a filler material in concrete but also acts as a binder. In addition to that, the cost analysis depicts reduced concrete cost. With the results observed, sawdust concrete could play an essential role as an alternative construction material. All things considered, this paper opens possibilities for future research of optimum sawdust concrete in reinforced cement concrete construction.

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