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Effectiveness in Addressing the Sustainability and Environmental Issue Involving Use of Coal Ash as Partial Replacement of Cement in Concrete

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Abstract: **-** Concrete industry is one of the largest consumers of natural virgin materials and its primary constituent cement is one of the main source of carbon dioxide emission during its manufacturing. For one ton of cement produced, one ton of carbon dioxide is released into atmosphere. In order to address environmental effects associated with cement manufacturing and constantly depleting natural resources, there is a need to develop alternative binders to make concrete industry sustainable. This work examines the possibility of using coal ash as partial replacement of cement for new concrete. In this study coal ash was partially replaced as 5%, 10%, and 15% in place of cement in concrete for M-25 mix and tested for its compressive strength and tensile strength up to 28 days of age and compared with conventional concrete. From the results obtained, it is found that coal ash can be used as cement replacement up to 5% by weight to prevent considerable decrease in strength and a fair increase in workability. For further increase in coal ash content, strength decreased considerably but workability increased.

Keywords: **-** *Compressive Strength, Slump, Splitting Tensile Strength, Coal Ash Concrete, Workability.*

I. INTRODUCTION

Concrete is the most used construction material in the world with over 25 billion tons (22.7 billion metric tons) placed each year [1]. Cement is one of the primary ingredients of concrete. The transformation toward sustainable development provides the concrete industry with a tremendous opportunity and responsibility to inform stakeholders about the new sustainable materials ability to not only enhance the built environment for people and communities but also to protect our planet "Earth" as well. The longevity of service of concrete structures continues to be a critical environmental asset, with beneficial impact on natural resource conservation, landfill use, and CO_2 reduction.

The global consumption of cement is very high due to its extensive use in concrete. Over 5 billion tons of cement is produced in the world per year. However, the production of cement is exploiting the limestone reserves in the world and also cement manufacturing requires a huge consumption of energy. River sand has been the prime choice for the fine aggregate component of concrete in the past, but overuse of the material has led to environmental concerns, the depleting of securable river sand deposits and an alarming price increase in the material. Thus there is the need to search for local materials as alternatives to ingredients of concrete for the construction of functional but low-cost infrastructure. Concrete can play a vital role in the way we conserve and protect natural resources in the structures we create with it and the processes by which we produce it. Concrete offers long-lasting service with minimal maintenance, along with recycled content and end-of-service recyclability. In its many forms, uses, and styles, concrete can reduce the need for additional building materials, operating energy in buildings and transportation, conversion of undeveloped land, retention ponds, and other traditional storm-water management systems.

Construction industries are in stress to identify alternative materials to replace the demand for natural sand and cement. On the other hand, the advantages of utilization of byproducts obtained as waste materials are pronounced in the aspects of reduction in environmental load and waste management cost, reduction of production cost as well as augmenting of concrete. To overcome the stress and demand for cement, researchers and practitioners in the construction industries have identified some alternative materials such as fly ash, slag, limestone-powder, siliceous materials and coal ash. In India, researchers have practiced the use of coal ash as partial replacement of cement in concrete and it yielded positive results. Coal ash is produced in various coal-fired power plants all over the world, which totals about 480 million tones according to a report submitted in 2001 [2]. India is ranked 4th in world with a total coal ash production of 80 million tones. Such a huge amount of coal ash needs to be disposed. But on considering the disposal, threat of serious environmental problems and requirement of vast land arrives. One of the options of disposal is utilizing the coal ash as ingredient of some material.

In this research cement was partially replaced by coal ash as 5%, 10% and 15% by weight. Concrete specimens were tested for slump, compressive strength and splitting tensile strength for different coal ash

percentages. The results obtained were compared with results of normal M-25 concrete mix and it was found that minimum decrease in compressive strength and splitting tensile strength occurred for the concrete mix containing 5% coal ash by weight of cement. Slump test was carried out on the fresh concrete and compressive strength test and splitting tensile strength test on hardened concrete. The concrete cubes and cylinders were tested at the ages of 7 day and 28 days. The slump increased as the coal ash content increased. The compressive strength decreased with increasing coal ash addition. It was concluded 5% coal ash substitution is adequate to enjoy maximum benefit of workability and insignificant decrease in strength. This paper summarized the behavior of concrete involving partial replacement of cement by coal ash as 0%, 5%, 10% and 15% by weight which may help to reduce the disposal problems of coal ash and enhance properties of concrete.

II. MATERIALS USED

2.1. Cement and Aggregates Khyber ordinary Portland cement of 43 grade confining to IS 8112 [3] was used throughout the work. Fine aggregates used throughout the work comprised of clean river sand with maximum size of 4.75mm conforming to zone II as per IS383-1970 [4] with specific gravity of 2.6. Coarse aggregates used consisted of machine crushed stone angular in shape passing through 20mm IS sieve and retained on 4.75mm IS sieve with specific gravity of 2.7.

2.2. Coal Ash Coal ash was collected as a residue from different coal scuttles which are used in chilly winters in Kashmir valley for heating purposes. It was sieved through 90 micron (µm) IS sieve. The specific gravity of coal ash was found to be 2.3. Chemical composition of coal ash is presented in TABLE 1. Fig.1 shows coal ash after sieving.

III. EXPERIMENTAL INVESTIGATION

3.1. Mix Proportion The concrete mix design was proposed by using IS 10262 [5]. The grade of concrete used was M-25 with water to cement ratio of 0.45. The mixture proportions used in laboratory for experimentation are shown in TABLE 2.

3.2. Test on Fresh Concrete Slump Test The workability of all concrete mixtures was determined through slump test utilizing a metallic slump mould. The difference in level between the height of mould and that of highest point of the subsided concrete was measured and reported as slump. The slump tests were performed according to IS 1199-1959 [6].

3.3. Tests on hardened concrete From each concrete mixture, cubes of size 150mm x 150mm x 150mm and 150mm x 300mm cylinders have been casted for the determination of compressive strength and splitting tensile strength respectively. The concrete specimens were cured under normal conditions as per IS 516-1959 [7] and were tested at 7 days and 28days for determining compressive strength as per IS 516-1959 [8] and splitting tensile strength as per IS 5816-1999.

IV. RESULTS AND DISCUSSION

4.1. Fresh concrete The slump values of all the mixtures are represented in TABLE 2. The slump increased with the increase in coal ash content. Coal particles absorbed less water as compared to sand and thus improving the workability of concrete mix. Slump was maximum for the concrete mixture containing 15% coal ash in place of fine aggregates. The variation of slump with waste coal ash content is depicted in Fig. 2.

4.2. Hardened concrete The compressive strength tests and splitting tensile strength tests are presented in TABLE 3. Compressive strength tests and splitting tensile strength tests were carried out at 7 and 28 days. A decrease in compressive strength was observed up to 15% replacement of cement by waste coal ash. The minimum compressive strength measured was 2% less than that of reference mix at 28 days corresponding to concrete mix containing 5% waste coal ash in place of cement. Splitting tensile strength decreased with increasing waste coal ash content. Fig. 3 and 4 present compressive strength of all mixtures at 7 and 28 days respectively. Fig. 5 and 6 present splitting tensile strength of all mixtures at 7 and 28 days respectively.

Fig.1 Coal ash after passed through 90 µm I.S. sieve.

TABLE-1. Chemical Composition of Coal ash

Materials	Percentage (%)
Silica(SiO_2)	63.67
Alumina(Al_2O_3)	13.43
Calcium oxide(CaO)	5.46
Magnesium Oxide(MgO)	2.46
Iron oxide(Fe_2O_3)	11.41
Potassium Oxide(K_2O)	1.03
LOI(Loss on ignition)	0.84

Table-2 Mix Proportion

Coal Ash %	w/c ratio	Water (Kg/m^3)	Cement (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coal Ash (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Slump (mm)
0	0.45	191.6	425.80	543.5	0.00	1199.36	28
5	0.45	191.6	404.51	543.5	21.29	1199.36	33
10	0.45	191.6	383.22	543.5	42.58	1199.36	34
15	0.45	191.6	361.93	543.5	63.87	1199.36	34

Table-3 Compressive strength and splitting tensile strength test results

Coal Ash %	Cube compressive strength (N/mm^2)		Cylinder splitting tensile strength (N/mm^2)	
	7days	28 days	7days	28 days
0%	22.88	32.13	2.32	3.25
5%	21.96	31.53	2.18	3.20
10%	20.76	30.38	2.11	3.04
15%	18.55	28.82	1.87	2.91

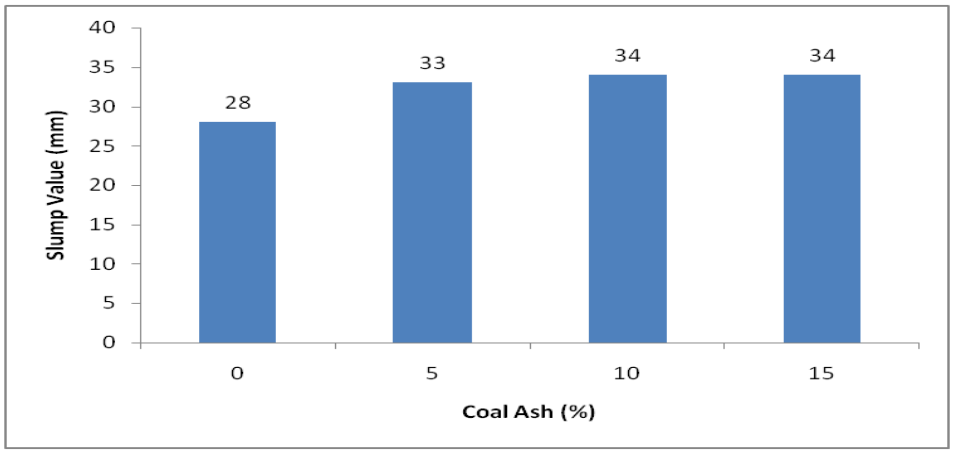

Fig. 2. Variation of slump with waste coal ash content.

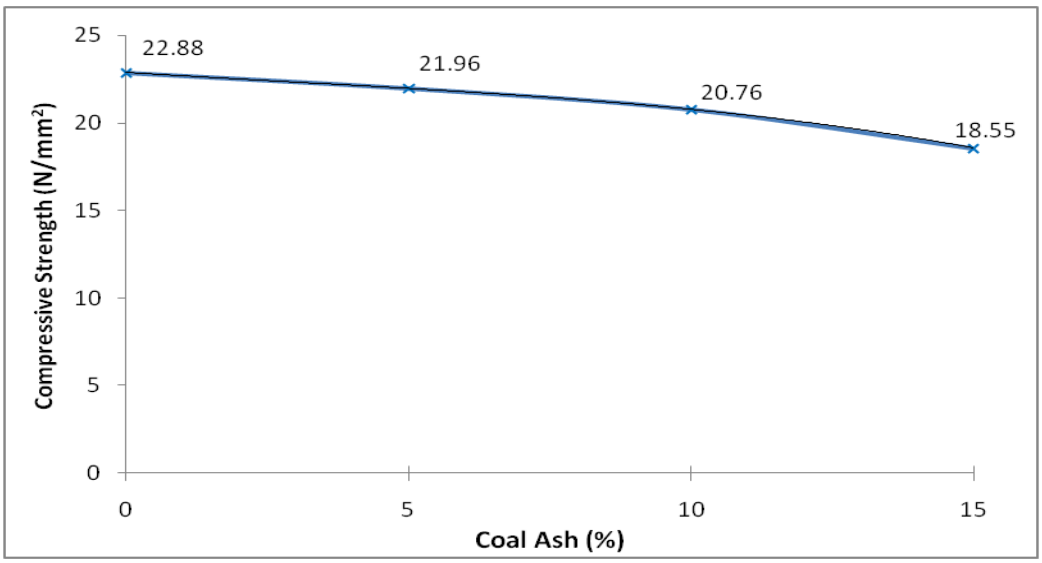

Fig. 3. Compressive strength of cubes at 7 days

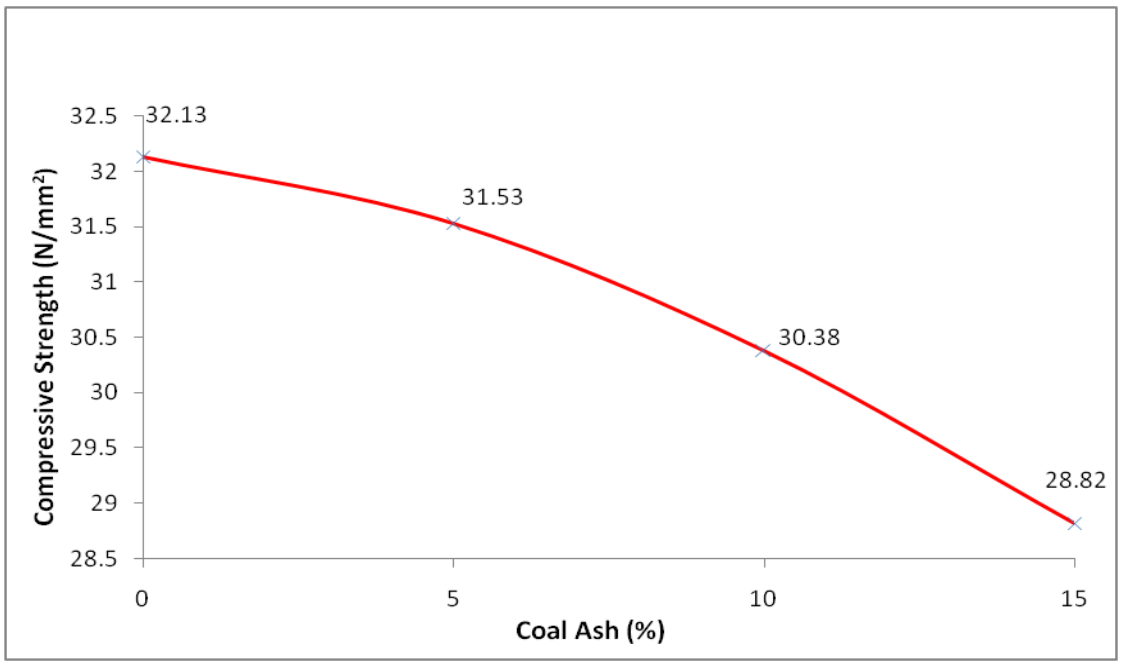

Fig. 4. Compressive strength of cubes at 28 days

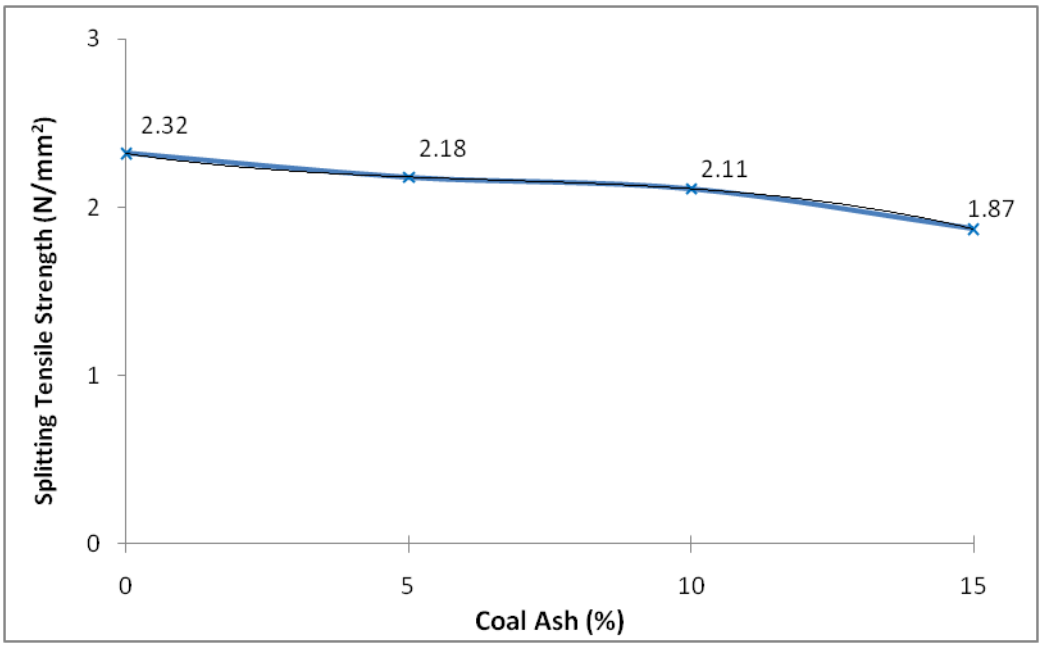

Fig. 5. Splitting Tensile strength of cylinders at 7 days

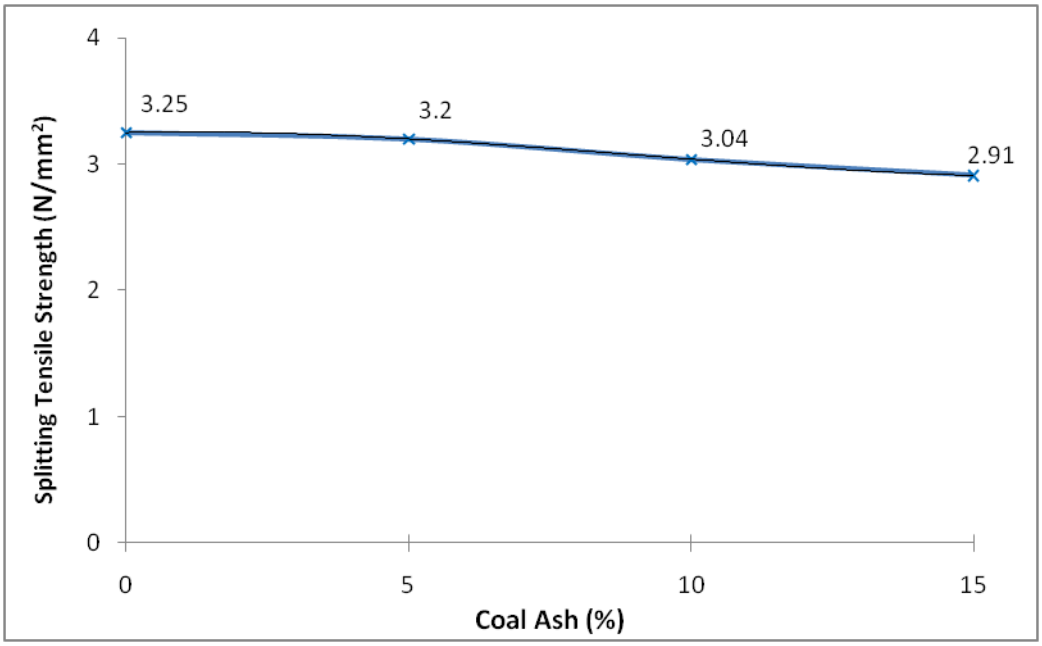

Fig. 6. Splitting Tensile strength of cylinders at 28 days

V. CONCLUSION

On the basis of results obtained, following conclusions can be drawn:

1. 5% replacement of cement by coal ash showed 4% decrease in compressive strength at 7 days and 2% decrease in compressive strength at 28 days. Further addition of coal ash showed significant decrease in both compressive as well as splitting tensile strength.
2. The optimum value for cement replacement is 5% as reduction in strength is low and increase in workability is considerable.
3. Workability of concrete mix increases with increase in waste coal ash content.
4. Use of waste coal ash in concrete can prove to be economical as it is free of cost.
5. Use of waste coal ash will eradicate its disposal problem and reduce carbon emissions (CO_2) thus proves to be environment friendly thus paving way for greener concrete.

In order to be sustainable for future generations we must fully exploit by-product materials like waste coal ash. This will reduce the greenhouse gas emissions. It is our duty to take sensible engineering judgments based on facts about byproducts and not on the prejudice of assuming a 'WASTE' is somehow inferior or less suitable.

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