Feasibility of Copper Slag – Fly Ash Mix as a Road Construction Material

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Abstract - **In this paper, an attempt has been made to study the feasibility of copper slag – fly ash mix for use in subbase course of the flexible pavements. A number of cylindrical test specimens (38 mm diameter and 76 mm height) were prepared with raw materials such as copper slag and fly ash in different proportions. These samples were cured at a temperature of 30^0C and relative humidity of 85% in a humidity controlled chamber for different curing period of 0, 7, 14 and 28 days. The geotechnical properties of different trial mixes, namely, unconfined compressive strength, soaked CBR and triaxial shear strength were determined. The effects of fly ash and content and curing period on the above geotechnical properties were investigated. From the present study the 30% fly ash +70% copper slag mix was found to be optimum for use in subbase layers of the flexible pavements. Therefore, construction of road pavements utilizing the optimum mix as stated above is possible. This will help in conserving the conventional aggregates used for subbase and eliminate problems related to disposal of industrial waste like copper slag and fly ash.**

Index Terms – **Copper Slag, Fly ash, Unconfined Compressive Strength, CBR, Triaxial Shear Strength**

I. Introduction

At present, India is in the phase of development and huge investments are being made in the up gradation of existing roads under National Highway Development Programme (NHDP) and construction of new roads under Pradhan Mantri Gram Sadak Yojna (PMGSY). Therefore, the naturally occurring materials are fast depleting because of their over exploitation to meet the huge demand for construction of infrastructure projects. In recent years, there has been a growing emphasis all over the world towards promoting the use of marginal materials in road construction in order to affect cost saving, reduce pressure on good quality aggregates and also to protect environment. A huge quantity of industrial by – products such as copper slag, steel slag, blast furnace slag, fly ash etc is generated all over the world and has problems of environmentally safe disposal.

It has been estimated that for every ton of refined copper produced, about 2.2 tonnes of slag is generated and every year, approximately 24.6 million tonnes of copper slag is produced from world copper production (Gorai et al., 2003). The total accumulation of copper slag in India till 2007 is about 10 million tons (Havanagi et al., 2008).Thakkar (2011) reported that in 2008 – 2009, nearly 160 million tonnes of fly ash was being generated in India from thermal power plants out of which about 80 million tonnes of fly ash was utilized in different commercial applications. Birla Copper Industries at Dahej, Gujarat produces roughly 0.5 million tones tons of copper slag per year and its captive thermal power plants produces 18000 tonnes of fly ash per year (Patel et al., 2007).

Das et al. (1983) obtained the angle of friction of copper slag between 40 and 52^0 and reported that ô value increased with relative density. Patel et al. (2007) studied the geotechnical properties of copper slag mixed with different percentage of fly ash (20, 25, 30, 35 and 40%) and observed the maximum CBR value of 32 for the mix of 80% slag and 20% fly ash. Havangi et al. (2007 and 2008) investigated the geotechnical properties of copper slag mixed with fly ash in the range of 25% to 75% and reported that copper slag – fly ash mixes with 75% slag content can be used in the subbase layer of road pavements. The detailed study on the effects of fly ash content and curing period on the geotechnical properties (UCS, CBR, modulus of elasticity, etc.) of the copper slag – fly ash mix has not been reported so far. In this context an attempt has been made to investigate the feasibility of copper slag- fly ash mix for use as a subbase material in the construction of the road pavements.

II. EXPERIMENTAL PROGRAMME

A. Materials

In the present investigation, copper slag were collected from Hindalco Industries Ltd. (Unit: Birla Copper) Dahej, Bharuch, Gujarat. Fly ash used in the experimental work was also collected from Hindalco Industries Ltd. (Unit: Birla Copper) Dahej, Bharuch, Gujarat. It was then stored in air airtight container for subsequent use. The physical properties of the raw materials are given in Table I.

B. Atterberg Limits

Atterberg limit tests were carried out as per IS: 2720 (part-V) 1985. The copper slag and fly ash were found to be non plastic in nature. This property is beneficial for use in sub base layer of road pavements.

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TABLE I. PHYSICAL PROPERTIES OF THE RAW MATERIALS

Physical Parameters	Copper slag	Fly Ash
Specific Gravity	3.24	2.38
Grain Size Distribution		
Gravel (%)	0	0
Coarse Sand (%)	21	0
Medium Sand (%)	72	0
Fine Sand (%)	7	11
Silt + Clay (%)	0	89
Coefficient of uniformity (Cu)	2.5	6
Coefficient of curvature (Cc)	1.74	2.67
IS Classification	SP	ML

C. Unconfined Compressive Strength Test

For the determination of unconfined compressive strength, copper slag was mixed with different fly ash content (10, 20, 30 and 40%) in dry condition. A right amount of water (close to OMC) was added to give proper consistency to the mixture for easy moulding. Cylindrical samples of 38mm diameter and 76mm height were then prepared by compacting the mix at their corresponding OMC and MDD. The samples were sealed in an airtight polythene bags and kept in humidity chamber for different curing period (0, 7, 14 and 28 days) under controlled temperature of 30^0 C and relative humidity of 85%. The unconfined compressive strength of these cured samples was then determined using a conventional compression testing machine at a constant strain rate of 0.6mm/min as per IS: 2720(Part X) – 1991.

D. CBR Test

California bearing ratio tests was conducted on copper slag as per IS: 2720 (part XVI) 1979 on the optimum mix for the subbase course, i.e., 30% fly ash + 70% copper slag. After compaction the CBR samples were sealed in airtight polythene bag and cured in humidity chamber at constant temperature of 30^0 C and relative humidity of 85% for a period of 0, 7, 14 and 28 days. The CBR samples were soaked in water for 4 days prior to testing.

E. Triaxial Test

Unconsolidated Undrained triaxial test was carried out on optimum mix, i.e., 30% fly ash + 70% copper slag as per IS: 2720 (Part XI) – 1993. Cylindrical samples of 38mm diameter and 76mm height were prepared and cured for a period of 0, 7, 14 and 28 days using the same procedure as explained earlier in section C. Triaxial tests were carried out on cured samples using a conventional compression testing machine at a constant strain rate of 0.6mm/min for three different cell pressures, i.e., 40, 80 and 120 kPa.

III. Results And Discussions

A. Unconfined Compressive Strength

Fig. 1 and 2 show the variation of unconfined compressive strength (UCS) with fly ash content and curing period, respectively, for various copper slag-fly ash mixes. The UCS value increases up to 30% fly ash content and decreases thereafter for all the curing period (Fig. 1). The fly ash particles are very fine in nature as compared to that of copper slag. Therefore, the fly ash particles fill the large void spaces between the particles of copper slag resulting in the formation of densely compacted mass giving higher strength. When the fly ash content is more than 30% (the optimum fine content), it remains as a weak filler in the mix resulting in the reduction of strength.

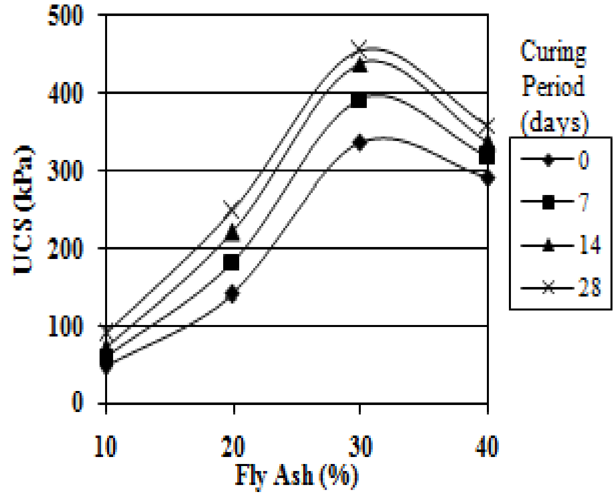

Fig 1. Variation of UCS with fly ash content

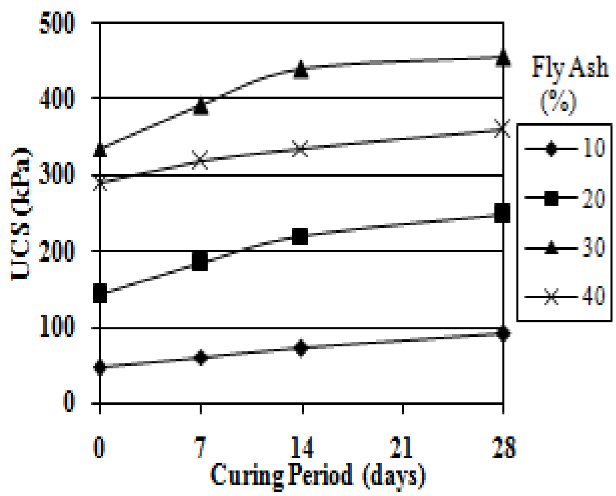

Fig 2. Variation of UCS with curing period

The UCS value increases continuously with increase in curing period for all mixes (Fig. 2). However, the rate of increase of the strength is high in the beginning but slows down beyond 14 days of curing period. The strength gain in copper slag-fly ash mixes with increase in curing period is mainly attributed to the pozzolonic characteristics of fly ash.

The pozzolonic reaction results in the binding of the slag and fly ash particles more efficiently which leads to the increase in the compressive strength.From the UCS test results of copper slag-fly ash mixes, it was found out that 30% fly ash + 70% copper slag (30F+70C) mix has the maximum UCS value. Hence, this mix may be recommended for use in the subbase course.

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B. California Bearing Ratio (CBR)

Fig. 3 shows the variation of the CBR value with curing period for the optimum mix, i.e., 30% fly ash + 70% copper slag (30F+70C). The CBR value of the mix increases with the curing period. However, the rate of increase is high in the beginning but slows down beyond 14 days of curing period. As discussed earlier in section 3.1 the increase in the curing period results in the binding of the slag and fly ash particles more efficiently which imparts strength to the mix. As per IRC: 37-2001, the minimum CBR value for the material should be 30 for use in the subbase course. The 30F+70C mix satisfies these criteria. Hence, this mix may be recommended for use in the subbase course.

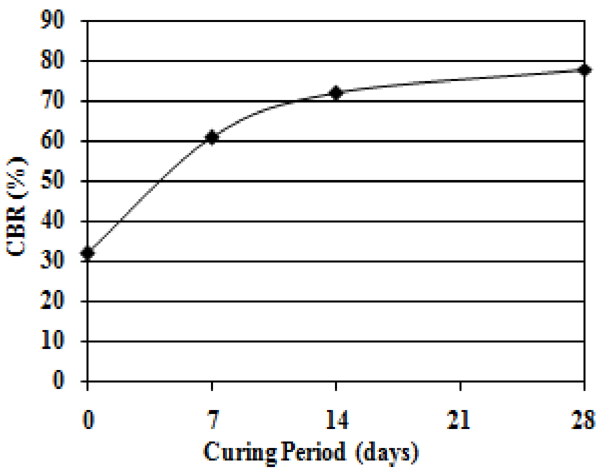

Fig 3. Variation of the CBR value with curing period

C. Triaxial Shear Strength

Unconsolidated Undrained triaxial tests were conducted on the optimum mix, i.e., 30F+70C at confining pressures of 40, 80 and 120 kPa. Stress-strain curves were drawn and the modulus of elasticity (E) was determined from the initial tangent to the curve. Fig. 4 shows the variation of deviator stress at failure with cell pressure and Fig. 5 shows the variation of modulus of elasticity with cell pressure. The deviator stress at failure and modulus of elasticity increases linearly with the cell pressure for all the curing periods. This is quite logical as the confinement of the sample increases its resistance to failure. The relationship between deviator stress at failure and modulus of elasticity with cell pressure is given in Table II.

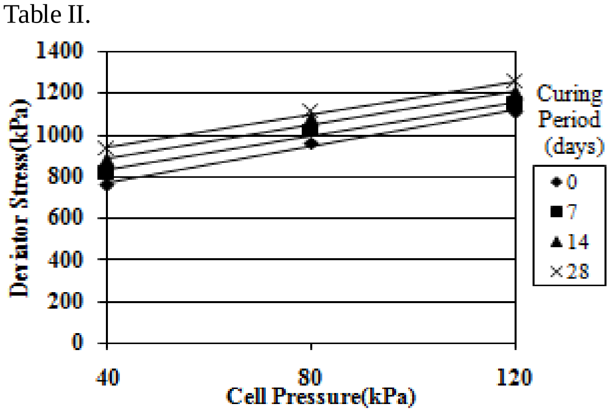

Fig 4. Variation of deviator stress at failure with cell pressure

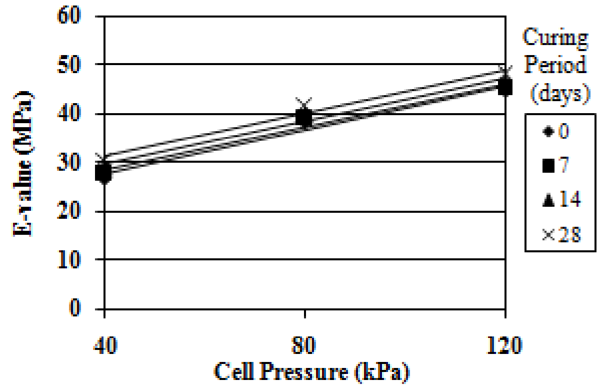

Fig 5. Variation of E-value with cell pressure

Table II. Relationship between deviator stress and modulus of elasticity with cell pressure for 30F+70C mix

Curing Period (days)	Relationship	
0	$\sigma_d = 4.375\,\sigma_3 + 592$	$E = 0.224\,\sigma_3 + 18.83$
7	$\sigma_d = 4.100\,\sigma_3 + 667$	$E = 0.220\,\sigma_3 + 19.8$
14	$\sigma_d = 4.037\,\sigma_3 + 725$	$E = 0.219\,\sigma_3 + 20.93$
28	$\sigma_d = 4.012\,\sigma_3 + 777$	$E = 0.218\,\sigma_3 + 22.83$

where, σ_d and σ_3 are in kPa and E is in MPa.

From Table 2 it can be seen that the highest coefficient is obtained for the 0-day curing period (unbound aggregates) indicating more dependency of σ_d and E on cell pressure, i.e., the effect of confinement is higher for unbound aggregates. With the increase in curing period, the binding of slag and fly ash particles increases due to which the mix behaves more as a bonded mass and hence the coefficient value decreases.

Fig. 6 shows the variation of deviator stress at failure with curing period and Fig. 7 shows the variation of modulus of elasticity with curing period for 30F+70C mix. The deviator stress at failure and modulus of elasticity increases with the curing period for all the cell pressures. With the increase in curing period more slag and fly ash particles are bonded together resulting in the increase in σ_d and E-value.

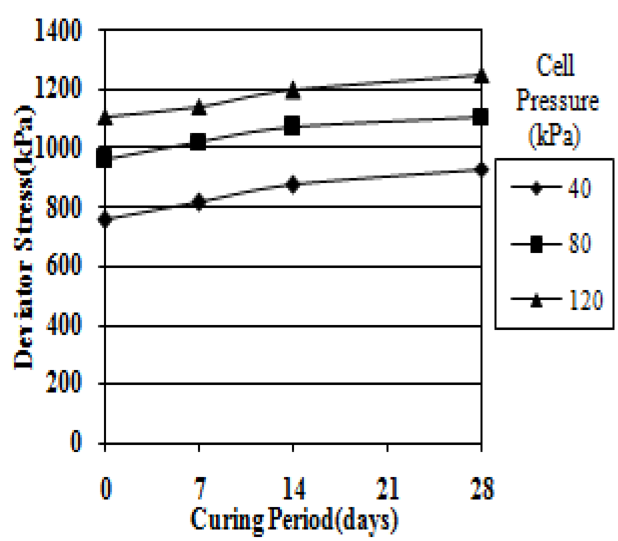

Fig 6. Variation of deviator stress at failure with curing period

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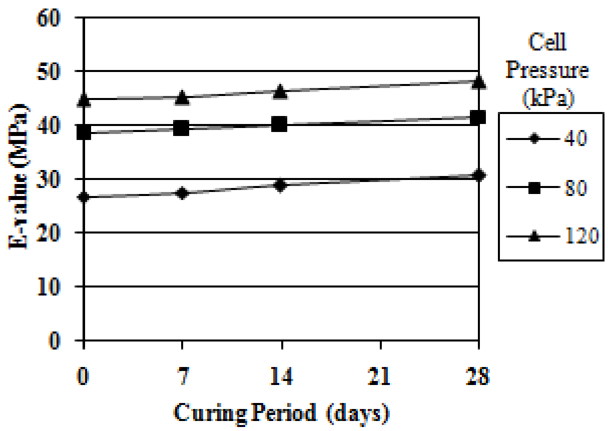

Fig 7. Variation of E-value with curing period

The deviator stress at failure and modulus of elasticity of 30F+70C mix are compared with that of the various pavement materials in Figs. 8 and 9 respectively. The failure deviator stress of 30F+70C mix is higher whereas the modulus of elasticity is lower as compared to that of coarse sand, stone dust and conventional subbase material.

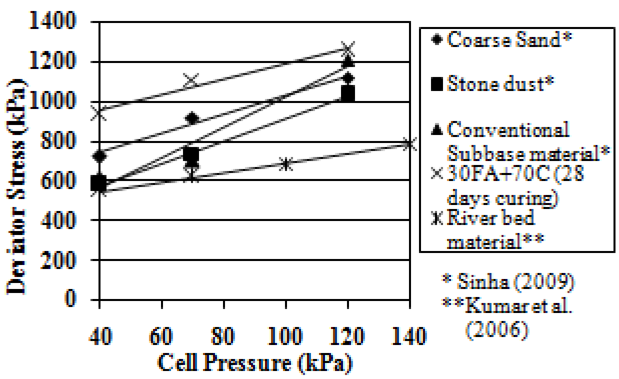

Fig 8. Variation of deviator stress at failure with cell pressure for various pavement materials

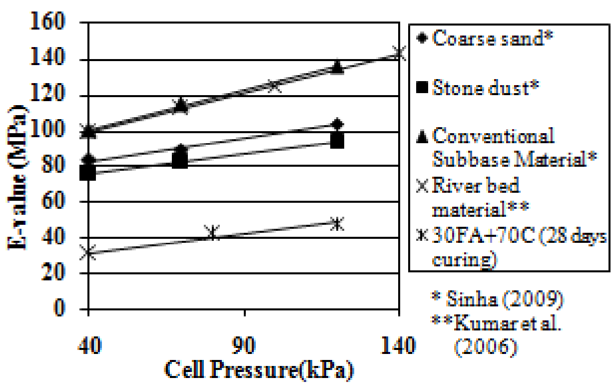

Fig 9. Variation of E-value with cell pressure for various pavement materials

CONCLUSIONS

From the present studies on the geotechnical properties of copper slag-fly ash mix,the following conclusions have been drawn:

i) Copper slag is a blackish material having specific gravity of 3.24. The high specific gravity is due to the high iron content. Copper slag and fly ash were found to be non plastic in nature.

ii) The compressive strength (UCS) increases with fly ash content up to 30% and decreases thereafter. Hence the mix 30% fly ash + 70% copper slag may be considered as the optimum mix. The UCS value increases continuously with increase in curing period for all mixes. However, initially the strength increases rapidly up to 14 days thereafter, the rate of increase slows down.

iii) The CBR value of the mix increases with the curing period. The soaked CBR value of the mix 30% fly ash + 70% copper slag was obtained up to 78 after 28 days of curing. This mix satisfies the minimum criteria for CBR value for use in subbase course as per IRC: 37-2001.

iv) The deviator stress at failure and modulus of elasticity increases linearly with the cell pressure. The dependency of σ_d and E on cell pressure decreases with increase in curing period. The values of σ_d and E increase with curing period.

v) The failure deviator stress of the optimum mix (30F+70C) is higher whereas the modulus of elasticity is lower as compared to that of coarse sand, stone dust and conventional subbase material.

vi) Based on the experimental findings it may be concluded that the mix 30% fly ash + 70% copper slag is suitable for use in the subbase layers of the flexible pavements.

The utilization of this mix in pavement construction will solve two problems with one effort:

(a) Solid waste disposal problems and

(b) Provision of needed construction material.

REFERENCES

[1] Das, B. M., Tarquin, A. J., and Jones, A. D., “Geotechnical properties of copper slag.” Transportation Research Record, 941, Washington, D.C., 1983, pp.1-4.

[2] Gorai, B., Jana, R. K., and Premchand, “Characteristics and utilization of copper slag - a review.” *J. Resources, Conservation and Recycling*, Elsevier Publication, 39, 2003, pp.299–313.

[3] Havanagi, V. G., Mathur, S., Prasad, P. S., and Kamraj. C., “Feasibility of copper slag-fly ash-soil mix as a road construction material.” *J. Transportation Research Board*, Washington, D.C., No.1989, Vol. 2, 2007, pp.13-20.

[4] Havanagi, V. G., Sinha, A. K., Mathur, S., and Prasad, P., “Experimental study on the use of copper slag wastes in embankment and pavement construction.” *Proc., Symposium on Engineering of Ground and Environmental Geotechnics*, Hyderabad, 2008, pp.259-264.

[5] IRC: 37-2001. “Guidelines for the design of flexible pavements.”[6] Kumar, P., Chandra, S., and Vishal, R., “Comparative study of different subbase materials.” *J. Materials in Civil Engg*., ASCE, Vol. 18, No. 4, 2006, pp.576-580.

[7] Patel, S., Vakharia, P. P., and Raval, S. M., “Use of copper slag and fly ash mix as subgrade and embankment fill material.” *J. Indian Highways*, Vol. 11, 2007, pp.17-22.

[8] Sinha, A. K., “Study on subbase materials for rural roads.” *Ph.d. dissertation*, Department of Civil Engg., IIT, Roorkee, India, 2009.

[9] Thakkar, A. R., “Environmental aspects of fly ash utilization and its regulation.” *Proc., Utilization of Fly Ash-2011*, Surat, 2011.

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