EFFECT OF COPPER SLAG IN SUBGRADE SOIL FOR DESIGN OF FLEXIBLE RUNWAY PAVEMENT

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DECLARATION

I Vanshika, hereby declare that the work presented in this thesis entitled "**Effect of copper slag in subgrade soil for design of flexible runway pavement"** in fulfilment of the requirement for the award of degree of Masters of engineering (Infrastructure engineering) submitted at Civil Engineering Department , Thapar Institute of Engineering & Technology (Deemed to be University), Patiala is an authentic record of work carried out under supervision of Er. Rajesh Pathak, Associate Professor, CED, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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Vanshika

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ABSTRACT

Preparation of subgrade for a transportation infrastructure on a problematic soil like clayey soil has always been a matter of great concern as clay can exhibit geotechnical problems like high compressibility, high plasticity, high swelling and shrinkage properties etc. To solve these problems and to improve the quality of soil, various soil stabilisation methods can be used. In our study, the properties of the clayey soil is improved by mixing the soil with industrial wastes like copper slag. Use of copper slag is done as it is way more cost effective and eco friendly options than others. The copper slag was collected from SYNCO industries, Jodhpur, Rajasthan and it was used to investigate the effect on locally available soil from Rajpura, Patiala, Punjab. Various proportions of copper slag (10%, 20%, 30%, 40%, 50%, 60% by weight of the parent soil) was used. The strength of the soil was observed by performing compaction tests, CBR tests etc. The observation of CBR tests explored that the CBR of the soil increases with increase in percentage of copper soil and hence the mix can be successfully used as a subgrade for flexible pavement for airport. FAARFEILD computer program is used to determine the pavement layer thickness.

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CHAPTER - 1

INTRODUCTION

1.1 GENERAL

For a developing country like India, industrialisation and urbanization is a must required activity to uplift the economy of nation and increase in the living standards of the people. But to provide a road system in the limited finances is the biggest handicap nowadays. The construction cost can be cut down by the usage of local soil and other local materials but sometimes the stability of locally available soils is not sufficient to support the wheel loads. So soil properties can be improved by using soil stabilization techniques. The subgrade soil for pavement can be stabilized economically instead of using costly paving materials. Industrialisation has caused serious environmental problems due to the disposal of industrial wastes in large amounts. The disposition of industrial wastes/by products is becoming difficult and costlier day by day due to the increase in the stringent environment rules and also due to the lack of suitable and nearby disposal sites. So the usage of industrial by products and wastages for soil stabilisation and other construction works is a good substitute, economically as well as environmentally.

Clay is the weakest soil for a subgrade due to the presence of kaolin, illite, smectite, and chlorite as these minerals cause volumetric change and swelling in the soil which further harm the structures. This problem can be controlled by stabilising the soil with copper slag.

Current study is an effort to increase the usage of copper slag as a stabilising material for soil and improve its characteristics. It has been the estimation that for one tonne of blister copper, 2.2 tonnes of slag is generated. Therefore if world copper production after smelting according to the copper statistics by U.S geological survey as of November,2010 was 15,900,000 tonnes then around 34,980,000 metric tonnes of slag is produced all over the world.

Some recent efforts have been made by few researchers to successfully use granulated copper slag as a highway construction material by using it in combination with local soils or other waste materials. However proper investigation through lab and field experiments is needed in the area of mass utilization of copper slag for road construction. Copper slag has found its applicability in various layers of pavement, be it flexible or rigid.

1.2 NECESSITY OF GROUND IMPROVEMENT

As it is known that all the load of the super structure of any construction project is always ultimately borne by the soil, therefore feasibility of soil is the primary concern for any geotechnical engineer. The characteristics of soil vary from one region to other and no two soils exhibit similar properties ever. For example a site may contain sandy soil which may further have the problems of liquifaction or the soil may be an expansive clayey soil causing problems like huge change in moisture content and so on. All these problems can be solved alternately by either

i. Abandoning the site all together
ii. Removing and replacing of the soil
iii. Redesigning the structure planned accordingly
iv. Treatment of the soil to modify its properties and using ground improvement techniques

1.3 SOIL STABILISATION METHODS

Soil stabilisation methods can be classified under two broad groups : One is soil stabilisation without using any additives and the other is soil stabilisation by using additives.

i. Stabilisation without using any additives
    a. Mechanical stabilisation : This methodology involves the improvement of soil by increasing the density of soil by compacting it or making a change in the gradation of the soil. This can be achieved in many ways like :
        I. Either by compaction of the soil,
        II. Or by removal or addition in the soil particles
        III. Or by method of blasting
    b. Stabilisation by using drainage :The effective stress on the soil is a major factor while discussing the strength of the soil. And the effective stress as we all know is largely affected by the ground water conditions like excess pore water pressure in the soil. So in this method the excessive pore water pressure is expelled out from the soil by using various methods given below :
        I. Applying some external load
        II. Using electro osmosis
        III. Applying thermal gradient

c. Ground reinforcement : In ground reinforcement following methods are used to help in the increase of the shear strength of the soil :

   I. By using stone columns or by nailing of soil
   II. Geosynthetics
   III. Grouting

ii. Stabilisation of soil by using additives: Different types of additives can be used in various types of soil in varying degrees to get different results .An additive is expected to considerably upgrade the soil quality . But all the results expected may or may not be achieved in one go. So for getting better results more than one additive can also be used at a time. Following are some the of various stabilisation options:

   a. Cement stabilisation
   b. Lime stabilisation
   c. Salt stabilisation
   d. Fly Ash stabilisation
   e. Bitumen stabilisation etc.

The choice of the method depends on various factors like degree and type of improvement required, type of soil and its characteristics, possibilities of damage to the nearby structures during and after stabilisation, durability of the additives involved, time available for the construction project and the cost effectiveness.

Moreover the pavement constructed on clayey soil requires a greater base and subbase thickness which adds to the already high cost of the project. So the option of increasing the strength of the soil becomes of utmost importance which will ultimately help in lessen the thickness of the layers of pavement and hence the cost of the project.

Large number of copper manufacturing plants are present in various parts of India and also the world from where several millions of tons of copper slag is churning out which is an absolute waste and of no use to the industry. Infact disposal of these wastes have become such a huge problem as they require a large chunk of land to be disposed on. But it has been researched by various people that it has high soil reform potential. Also it has negligible or no production cost.

1.4 COPPER SLAG

Since the beginning of the industrial area, slags which can be best described as the glassy materials which are left over after the pyrometallurgical extraction have been labelled as waste. One of those waste materials is copper slag that is produced by the process of matte smelting and the conversion of pyrometallurgical production of copper. Two different types of liquid get formed during the process matte smelting and these are copper - rich matte which are sulphides and the second one are slags which are oxides. Estimation have been done that if one tonne of copper is produced then 2.2 tonnes of copper slag is generated annually. So in total it has been estimated that around 24.6 million ton of slag is generated each year from the total worldwide production of copper. Slags which contain $< 0.8\%$ copper is discarded as waste or they are sold as products which have properties exactly like it. For example: Natural basalt in crystalline form or obsidian in amorphous form. The type of slag decides the utilisation and recovery of slag. During the process of smelting impurities become as slag which starts to float on the molten metal. When that slag is quenched in water, angular granules are produced which are disposed as waste.

1.4.1 Characteristics

The slag which is mechanically concentrated before the process of smelting mainly consists of silicon oxides and iron oxides. In appearance, copper slag is black, glassy and have granular particles. However it can be crushed partially leading to smaller particles after its refining is done. Copper slag has very good soundness properties, has good stability and also good resistance for abrasion.[Gorai et al. (2002)]. Since copper slag contains a very low amount of calcium oxide , therefore it exhibits pozzolanic properties.

1.4.2 Applications

1. Sandblasting: Since granulated copper slag is abrasive in nature therefore it is mainly used for surface blast cleaning. In this process the abrasive grains of copper slag grit are propelled towards work piece. Copper slag as blasting media is less harmful to environment and people than sand and meets the most of the rigid ecological and health standards.
2. Construction: Copper slag has been successfully used as partial replacement for sand in concrete production. The granulated slag having size fraction < 3 mm has some insulating and drainage properties which are helpful to avoid cracks in pavement caused due to the winter frost.

Present work makes use of the copper slag with soil and to study the changes in geotechnical properties of soil and further find its suitable application.

1.5 NEED FOR PRESENT STUDY

In various parts of our world, countries like India, Egypt ,USA etc. are facing many problems in construction projects due the problematic nature of clayey soil. Cases of damage to road structures have been in abundance. In this situation, methods like replacement of the soil and disposal of the previous one becomes quite a costly process and it is even more difficult in developing country like India where already the construction prices are soaring high.

1.6 OBJECTIVE OF STUDY

The study is focussed on the following points:

i. Improvement of locally available soil using some eco-friendly and cheap waste materials.
ii. Evaluation of strength characteristics of virgin as well as blended soil using different proportions of copper slag.
iii. Determination of appropriate soil and copper slag ratio to achieve the maximum gain in strength from the mix.
iv. To design the flexible pavement for airport and to determine the thickness of the pavement layers using a computer program called FAARFEILD.

1.7 OUTLINE OF THESIS

The thesis is primarily divided into six chapters:

Chapter 1 gives the general introduction of the industrial wastes, copper slag and soil stabilisation techniques.

Chapter 2 describes the thorough literature review on the effect of copper slag on the geotechnical properties of soil and on the subgrade of the pavement.

Chapter 3 gives us an insight as to what were the tests were performed on the soil and their detailed procedure explanations.

Chapter 4 describes the results and discussions where the analysing of all the experiments performed is done.

Chapter 5 includes the design of flexible runway pavement using computer program FAARFEILD.

Chapter 6 is the concluding chapter.

CHAPTER - 2

LITERATURE REVEIW

The literature discussed in this chapter focuses on the need of soil stabilisation, advantage of using industrial wastes like copper slag for stabilisation of soil, change in the geotechnical properties of the soil due to copper slag addition and the feasibility of the mix to be used in pavement subgrades and subbases. Given below some of the investigations performed and study of their outcomes done by the researchers in the past.

Gupta R.C et al. (2012) has experimented with the copper slag produced from 'Hindustan copper limited', Khetri , Rajasthan, India. It was producing 120 to 130 lakh of copper slag per annum . The soil used in this experimental program was classified as low plasticity clay (CL) according to Indian standard soil classification system (ISSCS). The copper slag used here has the uniformity coefficient of 4.6.The particle size analysis of copper slag was done by sieve analysis. At the mixing of copper slag in different percentages in clay , the specific gravity of the mix was found to be decreasing with the increasing amount of clay. The specific gravity of copper slag and clay was found to be 2.99 and 2.57 respectively.[4]The maximum dry density and optimum moisture content of the clay are determined to be 1.573 g/cc and 18.085 % respectively and the corresponding values for copper slag were 1.703 g/cc and 11.92 % respectively. The copper slag which was used in the experiments had silica as 71.52 % . The total sum of three oxides which is silica, alumina and iron oxide is 92.12 % which is way more than the required 70 percentile requirement for class N raw and calcined natural pozzolanas. Therefore copper slag was expected to have high quality pozzolana potential. The test results concluded that the absolute maximum dry density was achieved for the mix of 50% clay and 50 % copper slag. In the tri axial test, the angle of shearing resistance for 50 % copper slag was 48^0. The combination of 70 % clay + 30 % copper slag to 30 % clay + 70% copper slag was found to be the most satisfactory combination for good soil stabilisation.

Baraskar.T , Ahirwar S.K. (2014) had studied the California bearing ratio of Black cotton soil using waste copper slag. In this paper the value of soaked CBR (4 days) was discussed . It came out to be 5.43 % for the combination of 72 % black cotton soil with 28 % soil but further it tends to decrease. In this study copper slag was collected from The Sterlite industries - 1 Limited located in New Delhi , India and the Black cotton soil was collected from Shri G.S Institute of Technology and sciences < Indore , Madhya Pradesh. the soil used here is classified as highly compressible clay (CH) as per ISSCS . This research concluded that if 22 % to 32 % of copper slag is added in the soil then it will help to improve the problematic soils . It was observed that 28% CS + 68% B.C soil was found to be the most satisfactory combination for using in the subbase of flexible pavements.

Chandrashekhar J et al. (2015) had reviewed the utilization of copper slag in geotechnical applications. It was observed that copper slag behaved similarly like medium sands and it was useful as a construction material in place of sands. For example in backfill of retaining walls and in the landfills for the construction of shallow foundations. Copper slag was found to have high angularity and and friction angle (52^{o})of aggregates which helps to provide stability and increases load bearing capacity. Also copper slag aggregates are found to be free draining and are insulated to frost suspection. It was analysed that copper slag can be used as an alternative aggregate in bituminous mixes. In this test it was observed that specific gravity of copper slag is found to be 3.49 which is relatively high due to considerable amount of iron oxide present in it. The grain size distribution of copper slag depicts that it is a coarse grained material having around 95 % sand size particles and by Indian standard classification system , it is observed to be well graded sand. It was observed that for the mix of 60%CS and 40% soil , the plasticity index of the soil was reduced by 40%. Also there was a change in the value of free swell index for the addition of 60% copper slag. The reduction in free swell index was found to be 20 to 30 % at the addition of copper slag. Maximum dry density of copper slag was noted down to be 1.90 KN/ m^3. The soil mixed with copper slag showed an increase in MDD and decrease in OMC. This happens due to the fact that voids of coarser particles are filled bys the finer particles. All these change in properties gives effective results for subgrade and subbase applications. Similarly decrease in the swelling properties and increase in density caused an increase in the CBR values. Increase in CBR is essential in poor-subgrade soils. The UC strength of the mix increases upto 50% when copper slag is added and there after decreases.

Quereshi. A et al. had studied the effect of copper slag and black cotton soil mix for subgrade improvement in pavements. Here the geotechnical properties like unsoaked CBR and Direct shear strength were determined. The copper slag was collected from Birla copper industries, Dahej, Gujarat, India. The sieve analysis showed that the soil used is a poorly graded soil and the copper slag is well graded sand since the value of coefficient of curvature for soil and copper slag is 0.516 and 1.02 respectively whereas the value of coefficient of uniformity for soil and copper slag is 11.4 and 2.83 respectively. The value of liquid limit ranged from

68.04% to 39.24 % for various proportions of copper slag. It was observed that due to the 10% addition of copper slag , there was reduction of 14.96% in the liquid limit and the maximum reduction was observed at 40% copper slag addition which 42.34%. The plastic limit tests were done and it was observed that addition of30% and 40% copper slag decreased the plastic limit of the mix. Maximum reduction in the plastic limit was observed by addition of 40% stabiliser to the soil.The CBR tests were also done in the laboratory andthe CBR value goes highest upto 4.98 with the addition of 40% copper slag in it.So the ratio of 60% soil + 40% copper slag was found to be useful in highway construction when CBR of this mix was compared with the relevant codal provisions.

Venkati. B, Nagaraju. A (2016) have studied the CBR of Black cotton soil using waste copper slag. The black cotton soil was collected from Shri GS institute of technology and sciences, Indore, MP. The soil was classified as highly compressible (CH).The optimum moisture content and maximum dry density of the BC soil was found to be 18 % and 1.58 g/ cc respectively. It was observed that the soaked CBR (4 days) for different proportions of copper slag were in the range 1.98 to 5.43 %.

Parvathi. S, Nelson. A (2016) has studied the effect of the copper slag on Kuttanad clay. Kuttanad clays are dark brown in colour and are medium sensitive alluvial deposits found in the Kuttanad region in the state of Kerala in India. The dominant mineral constituents in this clay are kaolinite and illite. These clays are highly compressible , low shear strength and high percentage of organic matter, which is unfavourable geotechnically. Materials used for soil stabilisation were lime and copper slag. UCS test was done on it and compressive strength was found to be increasing with copper slag content upto 6% and decreasing thereafter. The mix 6% copper slag + 6% lime may be considered as optimum. The CBR value of soil gets improved when treated with lime and copper slag as the unsoaked CBR value for 7 day curing was 40.76 and that of soaked was 18.38.

Reddy P.V.S, Nanthakumar S (2016) investigates the improvement in the properties of clay soils with copper slag and lime. Lab tests are carried out on two different types of soils . First one was intermediate compressible and the second one was highly compressible. The results show that in both the type of soils the strength properties increased by increasing the percentages of copper slag and lime and the maximum strength was obtained at 30 % copper slag and 6% lime for 16 % water content for intermediate compressible soil. For highly compressible soil, it was at the mix of 30% copper slag and 6% lime at the water content of 15%.

Ravi E et al. (2016) has taken three different fractions to experiment upon and those are different variations of copper slag i.e, 10% copper slag, 20% copper slag , 30% copper slag. The results show that the combination of 70% soil with 30% copper slag is the compatible stabilization ratio which increases all the desirable characteristics of subgrade requirements.

Mohan chand A. et al. (2017) has studied the behaviour of black cotton soil with addition of copper slag. The soil was collected from Vempalle, Kadapa district from a depth of 1.5 m from the natural ground level The soil samples had 20% copper slag. The copper slag used here was collected from Apple insulated wires P.Ltd at Hyderabad, Andhra pradesh. From this investigation it was concluded that by increasing the percentage of copper slag dry density of soil acheived a maximum value of 1.69 g/cc at 20% copper slag mix . For this mix the unsoaked increased percentage of CBR came out to be 100.4 % and soaked increased percentage came out to be 149.2 %.

Mohanraj. P et al. (2017) investigates the clayey soils stabilised with copper slag and lime. Both the materials were used in different proportions ranging from 25% to 75%. The maximum strength was obtained at the mix of 50% copper slag + 50% lime with 15% moisture content for intermediate compressible soils. Copper slag used in this project was brought from Sterlite industries, Ltd. (SIL), Tuticorn, Tamil nadu, India. The value of maximum dry density was observed to be 1.656 g/ cc and the optimum moisture content was observed to be 15%. The unconfined compressive strength of soil with copper slag and lime waste came out to be 59.23 KN/m^2. It was observed that the combination of 90% clay with 10% copper slag and lime waste is the best combination to get good stabilisation.

Patel P. et al.(2017) investigates the improvement of expansive soil by the usage of copper slag.Following tables describes the chemical constituents in the copper slag used.

Table 1.1 Chemical composition of copper slag (Ankleshwar, Gujarat, India)

Iron Oxide	42 to 48%
Silica	26 to 30%
Aluminium oxide	1 to 3 %
Calcium Oxide	1 to 2%
Magnesium oxide	0.8 to 1.5%

The physical properties of copper slag were determined which are as shown in the table below :

Table 1.2 : Physical properties of copper slag

Property	**Value**
Hardness	6-7
Granule shape	Angular, Multifaceted and have sharp edges
Specific gravity	3.51
Plasticity index	Non - plastic
Swelling - index	Non - swelling
Particle size analysis	
Gravel %	1.00
Sand %	98.90
Silt+Clay %	0.05

Therefore it is clear from the table that most of the particles of copper slag here are coarsely grained. In fact sandy sized particles are around 95 % in the copper slag and observing at the particle size analysis of the copper slag and according to the Indian standard classification the copper slag here can be classified as poorly graded. It was observed that 30% when copper slag was added with locally available soil, the plasticity index of the soil was reduced by 15%. It was found that the mix of copper slag and local soil becomes non-plastic in nature. The free swell index decreased from 115% to 76% for the soil at 30% copper slag content in the mix. It was observed that maximum dry density of copper slag shows increase and optimum moisture content shows decrease in the value if copper slag was mixed in the proportion of 30% to 45%. The value of maximum dry density in case of copper slag was determined to be 1.755 g/cc at an optimum moisture content of 16.50%. So an inrease in the value of maximum dry density and decrease in the value of optimum moisture content is observed due to the addition of copper slag. Following graph shows the values of increased MDD and decreased OMC.

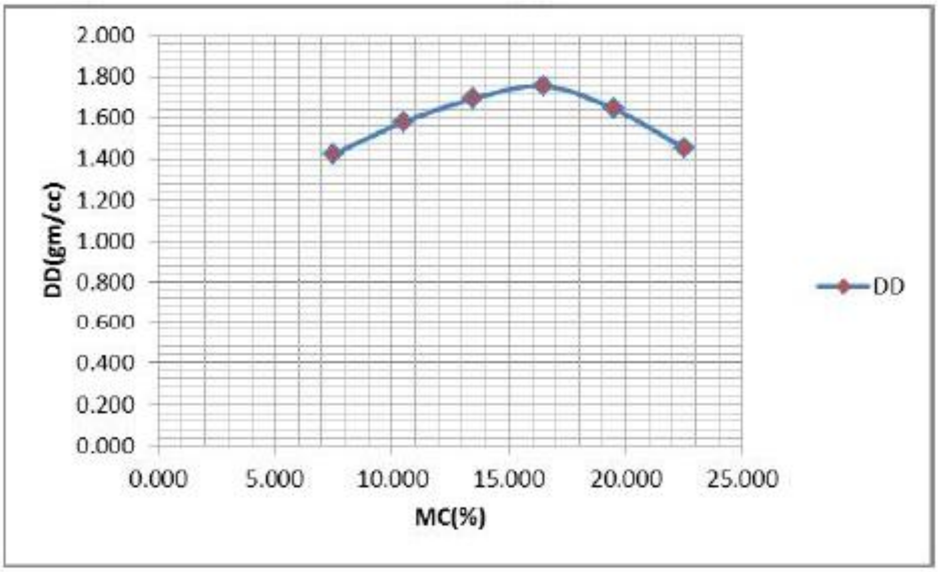


Figure 1.1: MDD vs. OMC graph at 30% copper slag in the mix

There were many conclusions to these observations:

i. It was determined that copper slag is a potential admixture to be used for improvement of expansive soil properties.
ii. The optimum proportion for copper slag to be mixed in the soil came out to be 30% to 45%.
iii. Copper slag can be used successfully for subgrade and subbases.

Kumar R.P(2017) has done the study on physical and geotechnical properties of expansive soils available at Pendlimari, Kadapa . The soil mix properties were studied at the copper slag variation of 10%, 20%, 30%, 40% and 50%.. The investigation resulted in that if copper slag is added in the range of 5% to 30% than the dry density increases from 1.46 to 2.06 and the percentage increase was calculated to be 48%. The unsoaked CBR value also increased from 1.80 to 6.32 that leads to a percentage increase in CBR of upto 67%.

Kavisri M. et al.(2017) has identified the usage of copper slag as a stabiliser for soils which are expansive. Three variations of copper slag were taken namely 10%, 20% and 30% and the tests for maximum dry density, Optimum moisture content, California bearing ratio and Unconfined compressive strength tests are done and results were compared with Indian standards for unconfined compressive strength. The result was that a significant amount of improvement was there in moisture content and maximum dry density.

Nawagamuwa U.P, Madhushanka H.K.P (2017) has observed that improving the weak subsoil conditions by mixing the cement has been widely used . But cement mixing is considered to be an expensive method. So copper slag which is an industrial by product is a good alternative and replacement for cement. Improvement of engineering characteristics of the samples were assessed by conducting direct shear tests, Proctor compaction tests, California bearing test. It was found that the 35% of copper slag mixed with given subsoil would provide the best performance.

CHAPTER-3

EXPERIMENTAL PROGRAMME

Experimental programme is the most important portion of the whole procedure. This involves collection of materials, methods of sampling and various tests conducted on these samples. During this programme, efforts have been made to optimise the geotechnical properties of the locally available soil such that its application in constructional activity becomes feasible.

3.1 MATERIALS

Two materials were used primarily. One is the locally available soil and other is the copper slag from a copper manufacturing industry. Below given are the physical and the chemical properties of the material used.

3.1.1 Copper slag

The copper slag was purchased from SYNCO industries Limited in Jodhpur (Rajasthan). This industry is a manufacturer of abrasive media. Copper slag was purchased for INR 5 per kg. The physical properties of copper slag used in experiments are such as the copper slag particles are found to be angular, having sharp edges and multifaceted. It was found to be black in colour, glassy and having shiny appearance.

Figure 3.1: Granulated copper slag

Copper slag consists of various chemical constituents. Following table depicts the chemical constituents of the copper slag collected from SYNCO industries and used in experiments :

Table 3.1: Chemical properties of copper slag from SYNCO industries ltd.

S.no.	Chemical component	% Chemical component
1.	Silica SiO_2 (combined as silicate)	26-30%
2.	Free Silica	< 0.5%
3.	Alumina Al_2O_3	1 - 3%
4.	Iron Oxide as FeO	42 - 48 %
5.	Calcium oxide,CaO	1 - 2 %
6.	Magnesium oxide , MgO	0.8 - 1.5%
7.	Copper oxide , CuO	0.60 - 0.70 %
8.	Sulphates	0.02 - 0.3 %

Since the main composition of copper slag is silicate and iron oxide, therefore copper slag has low melting point. Since calcium oxide is present in very low amount, therefore copper slag depicts pozzolanic properties.

The sieve analysis for copper slag was performed. Following table gives us the variation of percentage weight retained and percent finer passing with respect to the sieve size.

Table 3.2: Sieve analysis of copper slag

Sieve size	% Wt. Retained	% Cum. Wt. Retained	% Finer passing
4.75 mm	0	0	100
2.36 mm	0	0	100
1.00 mm	29.7	29.7	70.3
600 micron	33.3	63	37
425 micron	23.95	86.95	13.05
300 micron	5.7	92.65	7.35
150 micron	0.8	93.45	6.55
75 micron	0.45	93.90	6.1
PAN	6.1	100	-

From table 3.2, it can be observed that the copper slag consists of 0% of gravel sized particles, about 93.9% of sandy sized particles and 0.5% of silty +clayey particles. So copper slag is coarsely grained. Due to this reason there is better interlocking of soil particles and copper slag particles which leads to good compaction properties. Fig. 3.2 shows the particle size distribution curve for the copper slag.

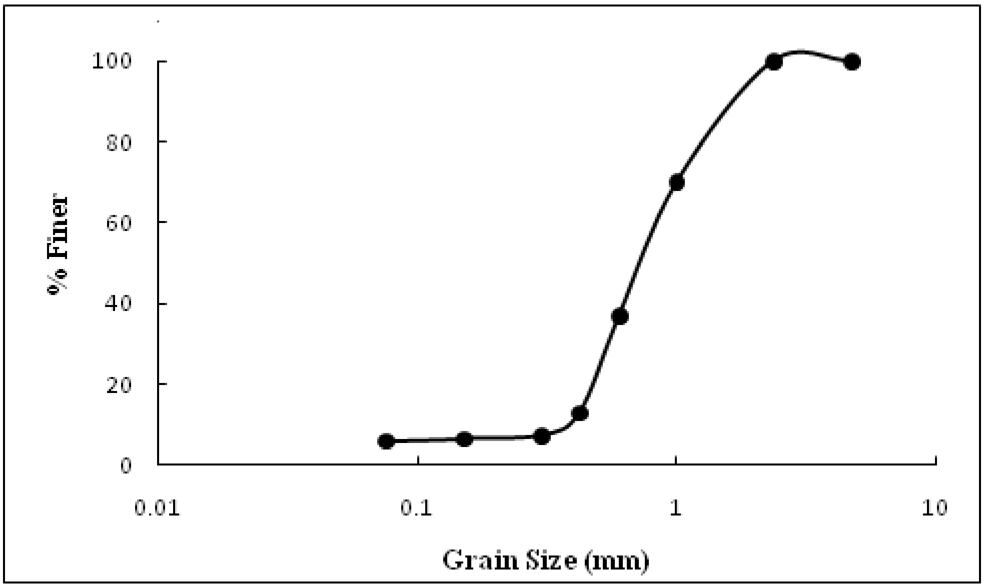


Figure 3.2: Grading curve for copper slag

3.1.2 Soil

The soil used in the experiments is locally available soil which is collected from the Rajpura region of Patiala, Punjab (India).The experimental investigations on this soil is done according to the Indian standard code. The soil was air dried in the oven for 24 hours before using in geotechnical tests.

Figure 3.3 : Soil used in experiments

Table 3.3 below depicts the findings of the sieve analysis done on soil.

Table 3.3: Sieve analysis of soil

Sieve size (micron)	**Wt. retained (gms.)**	**Cumulative Wt. Retained (gms)**	**%Cumulative Wt. retained**	**%Finer Passing**
600	0	0	0	100
425	45	45	4.5	95.5
300	63.5	108.5	10.85	89.15
150	515	623.5	62.35	37.65
75	143.5	767	76.7	23.3
PAN	233	1000	100	-

By using the observations from mechanical sieve analysis and comparing it with the Unified Soil Classification System, the soil can be classified as silty in nature. On the basis of the table above, a gradation curve for the soil is depicted below.

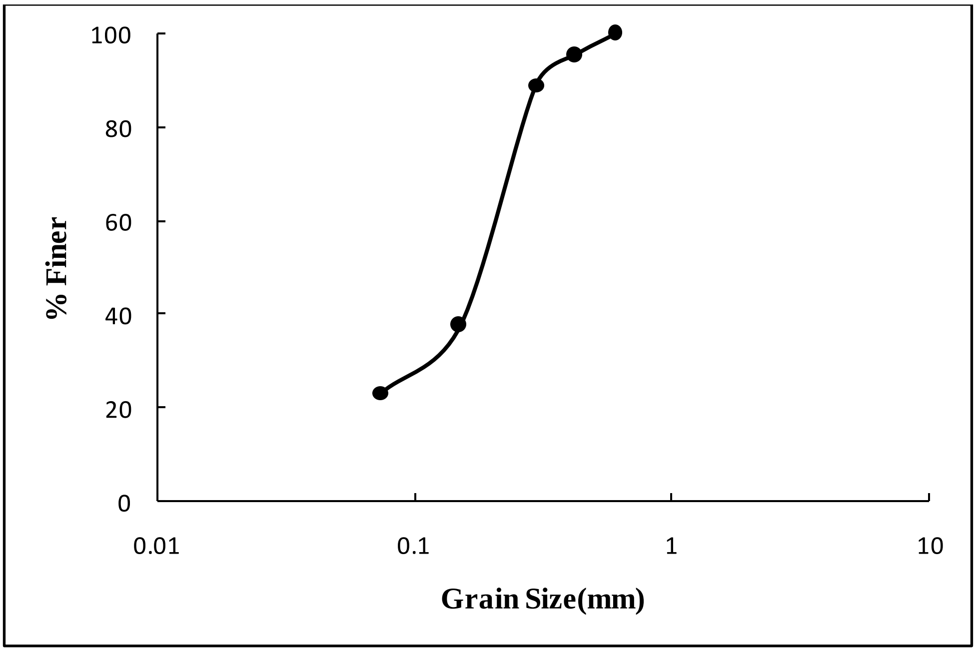


Figure 3.4: Grading curve for soil

Table 3.4 depicts the Atterberg's limits of the soil.

Table 3.4: Liquid limit, Plastic limit, Plasticity index of soil

Characteristics	Value
Liquid limit	24.3%
Plastic limit	15.8%
Plasticity index	8.5

3.1.3 Copper slag - Soil mix

The copper slag was added in various proportions to the soil. Following is the image of copper slag-soil mix used in the laboratory.

Figure 3.5: Air dried soil mixed with copper slag

The different mixes of copper slag and air dried soil are designated with specific specimen ID's which are as described in table below:

Table 3.5: Specimen ID

S.No.	Specimen ID	Sample Specification
1.	C	Base soil
2.	CS10	10% Copper slag + 90% Soil
3.	CS20	20% Copper slag + 80% Soil
4.	CS30	30% Copper slag + 70% Soil
5.	CS40	40% Copper slag + 60% Soil
6.	CS50	50% Copper slag + 50% Soil
7.	CS60	60% Copper slag + 40% Soil
8.	CS70	70% Copper slag + 30% Soil

3.3 METHODS

Following are the experimental methods which were used :

a) Mechanical sieve analysis

Mechanical sieve analysis is done to find the gradation characteristics of both the materials used- copper slag and the soil. The soil classification was also done on the basis of this sieve analysis. The sieves used during the process were 4.75 mm, 2.36 mm,1.00 mm,600micron,300 micron,150micron and 75 micron.

b) Standard proctor test

This test was performed according to IS 2720 Part VII 1980. Standard proctor test was done to basically find the maximum dry density and optimum moisture content of the soil. Due to this test a pattern was obtained for dry density as well as optimum moisture contents at various mixes of copper slag with soil.

c) Liquid limit and plastic limit tests

These tests were performed in accordance with IS 2720 Part 5 (1985). The tests for liquid limits and plastic limits were basically done to obtain the plasticity index pattern for various copper slag mixes and a linear trendline was successfully obtained at the end.[6] Liquid limit tests and plastic limit tests were also helpful in determining the plasticity index of the mixes and hence to know the plastic nature of the soil.

d) California bearing ratio test

This test was performed on the guidelines of IS 2720 part 16-(1973). California bearing ratio tests were done for soaked conditions (4 days). It was done for various proportions (0%, 10%, 30%, 50%, 60%) of copper slag in the mix and to check whether copper slag can be successfully used in subgrade mix or not. In the end a linear increase in the CBR strength of the copper slag- soil mix was obtained.

Below are the images of the laboratory work done during CBR tests.

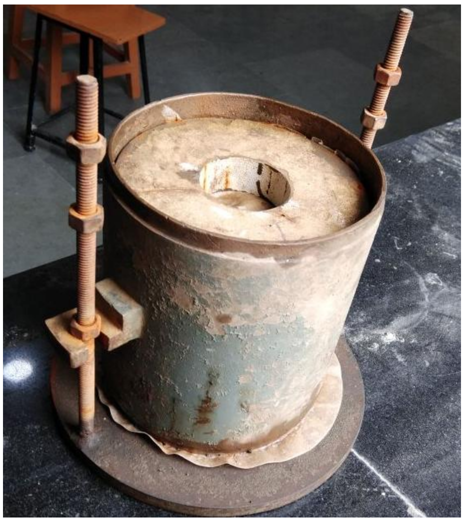


Figure 3.6: CBR Split mould

Figure 3.7: CBR loading machine

CHAPTER-4

RESULTS AND DISCUSSIONS

In this chapter, results of the various experimental investigations performed are discussed and analysed. Various tests were performed to observe a certain geotechnical pattern in the behaviour of the soil when blended with different proportions of copper slag. These specific patterns are depicted through different curves and graphs which are as discussed below:

4.1 EFFECT OF COPPER SLAG ON PLASTICITY INDEX

The tests for liquid limit and plastic limit were performed and plasticity index were found out for each mix. The tests were done according to the guidelines of IS 2720-5. As we can see from the table below that the liquid limits as well as plastic limit for unblended soil is linearly decreasing. So the plasticity of soil has decreased with the increase in the copper slag in the mix. The plasticity index of the soil has reduced to 1.585 % at 60% copper slag from that of 8.5% with no copper slag.

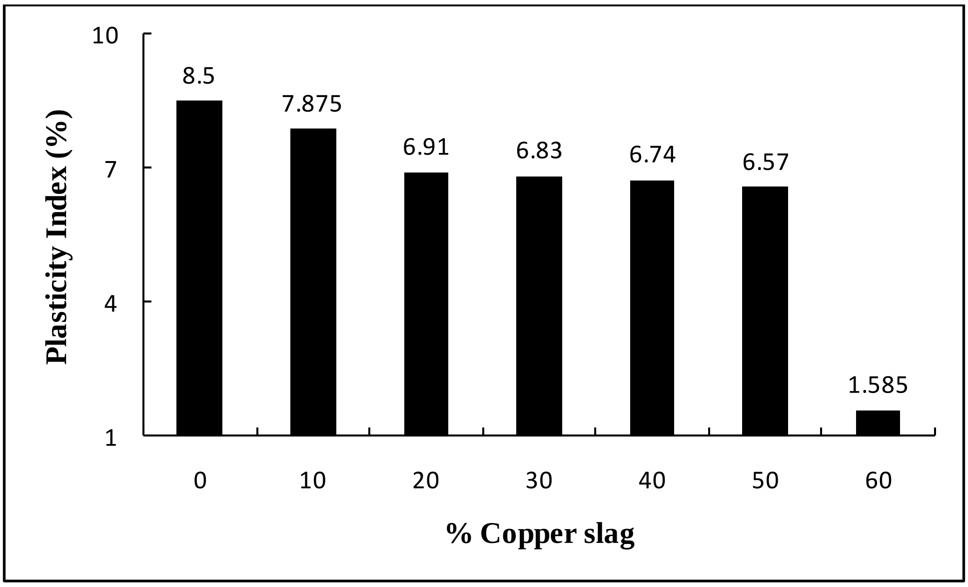
It can be noted from table 4.1 that the plastic limit and plasticity index value could not be inferred at 70% of the copper slag. This is because the plastic limit test could not be performed after a certain point as the thread used for experiment used to crumble before forming into 3 mm dia. So the test for plastic limit failed after 60% of copper slag in the mix.

Table 4.1: Variation of liquid limit, plastic limit and plasticity index with % CS

S.no.	Specimen ID	Liquid limit(%)	Plastic limit(%)	Plasticity index
1.	C	24.3	15.8	8.5
2.	CS10	20	12.125	7.875
3.	CS20	21.4	14.49	6.91
4.	CS30	13.58	6.75	6.83
5.	CS40	9.665	16.405	6.74
6.	CS50	12.2	5.63	6.57
7.	CS60	12	10.415	1.585
8.	CS70	8.8	-	-

The tests for plastic limit have started to fail due to increase in the proportion of copper slag in the mix. As the mix is not homogeneous after a certain point and therefore further compaction of the mix is not possible. So the experiments were restricted upto 60% of copper slag in the mix.

Fig. 4.1 shows the variation of plasticity index with the change in copper slag. The maximum rate of change was observed when 60% of copper slag was added and the percentage change was found to be 75.87%. The plasticity index of the mix was successfully reduced to a minimum of 1.585 % from the original value of 8.5%.



.Figure 4.1: Variation of plasticity index with % copper slag

It can be inferred from the graph above that plasticity index of soil decreases with increase in percentage of copper slag in soil. Therefore the soil becomes non-plastic in nature with the addition of copper slag.

4.2 EFFECT OF COPPER SLAG ON COMPACTION PROPERTIES

Compaction test enabled to get curve between dry density and moisture content at various copper slag proportions.

Fig.4.2 depicts the dry density vs. moisture content graph for unblended soil i.e, soil with no copper slag in it. It can be observed that the graph gave the value of maximum dry density as 18.7 kN/m^3 at an optimum moisture content of 13.82%.

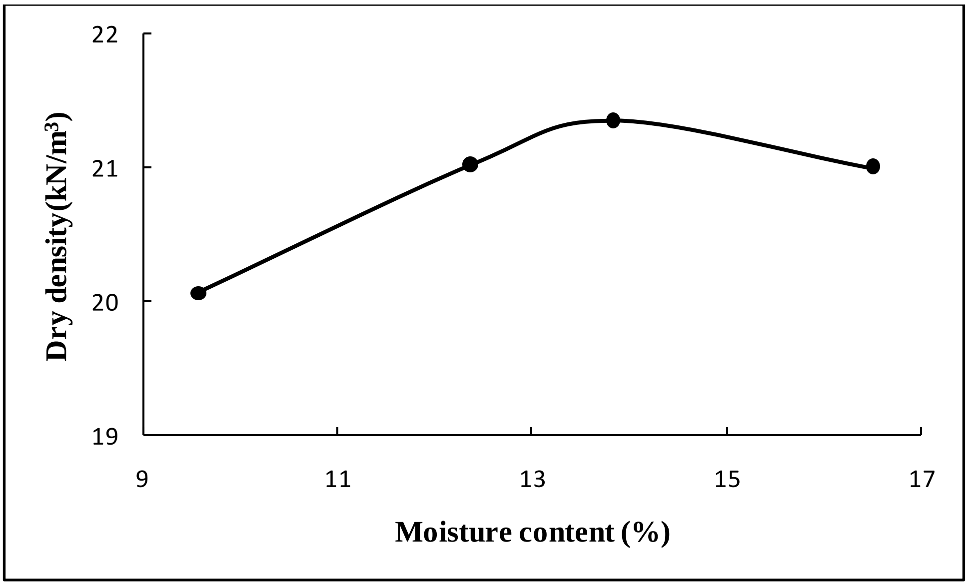


Figure 4.2: Dry density vs. Moisture content for virgin soil

Fig. 4.3 depicts the graph between dry density and moisture content when soil is blended with 10% of copper slag. Clearly, the maximum dry density came out to be 19.19kN/m^3 at an optimum moisture content of 12.62%. A decrease of 8.68% was observed in the optimum moisture content as compared to that of unblended soil. Also an increase of 2.62% was observed in the value of maximum dry density.

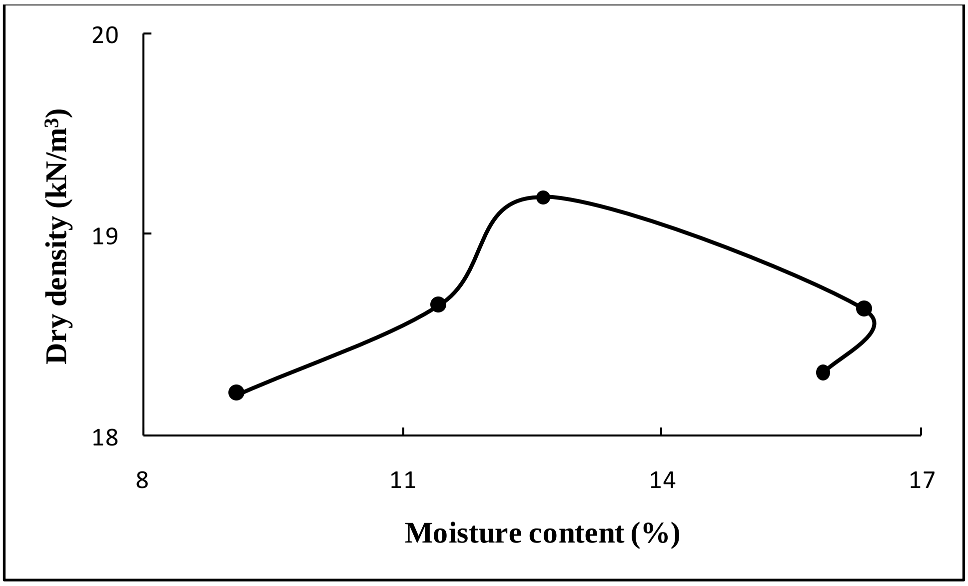


Figure 4.3: Dry density vs. moisture content (Copper slag 10% + Clay 90%)

Fig.4.4 depicts the variation of dry density with moisture content when copper slag in the soil is 20%. From the graph we can observe that the maximum dry density of the mix is 21.57 KN/m^3 at an optimum moisture content of 11.88%. So clearly there is a percentage increase of 12.4% in the dry density and a percentage decrease of 5.86% in optimum moisture content when compared with previous case of 10% copper slag.

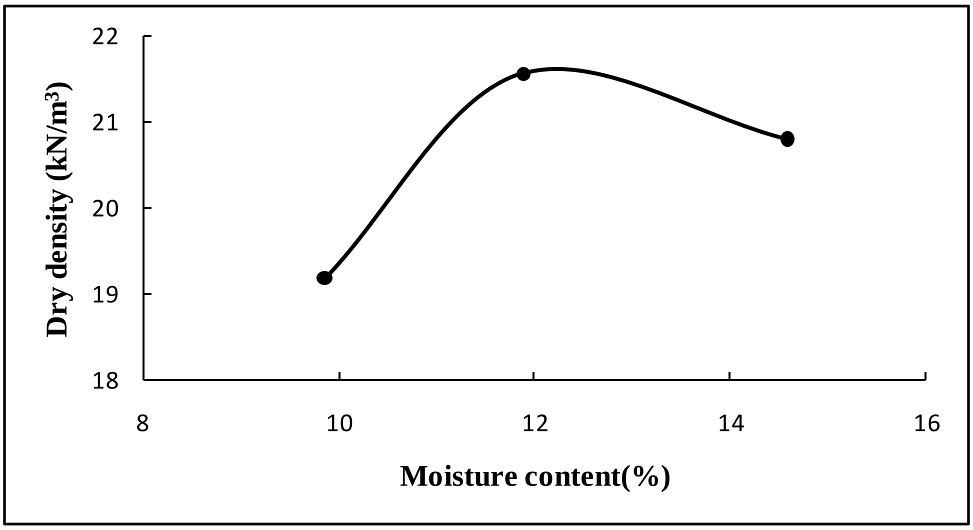


Figure 4.4 Dry density vs. moisture content (Copper slag 20% + 80% Clay**)**

In fig. 4.5, the graph shows us the variation of dry density with moisture content at a copper slag proportion of 30%. From graph the maximum dry density can be observed as 21.34 KN/m^{3}at an optimum moisture content of 11.34%. Clearly there is a percentage decrease of 1.06 % in the value of maximum dry density and a percentage decrease of 4.54 % in the value of optimum moisture content when compared with the previous case of 20% copper slag in mix.

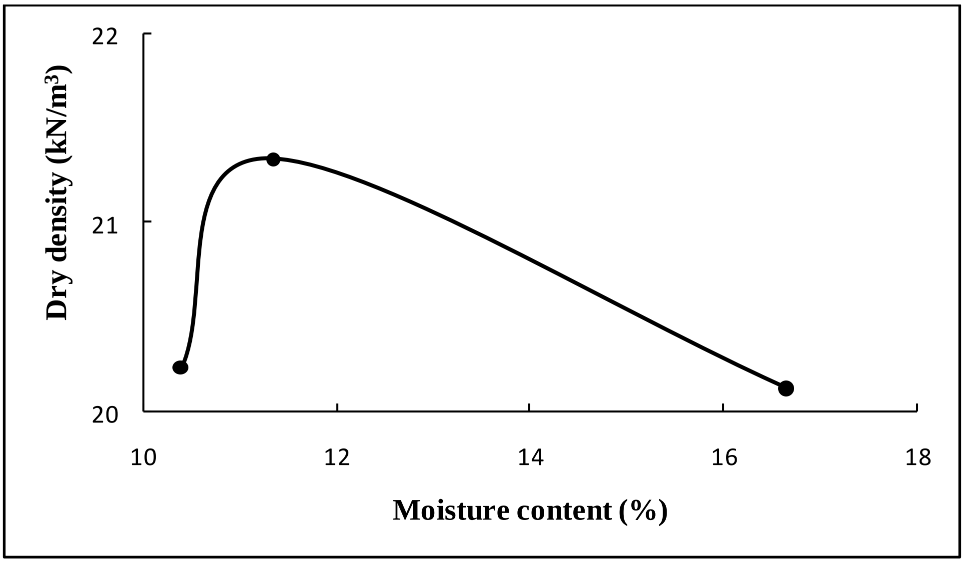


Figure 4.5: Dry density vs. moisture content (30% copper slag + 70% soil)

Fig. 4.6 depicts the dry density vs. moisture content graph for 40% copper slag in the mix. The maximum dry density in this case came out to be 21.756 KN/m^3 at an optimum moisture content of 10.36 %. So there is a percentage increase of 1.95% in max. dry density and a percentage decrease of 8.64% in OMC when compared to the previous case that is of 30% copper slag.

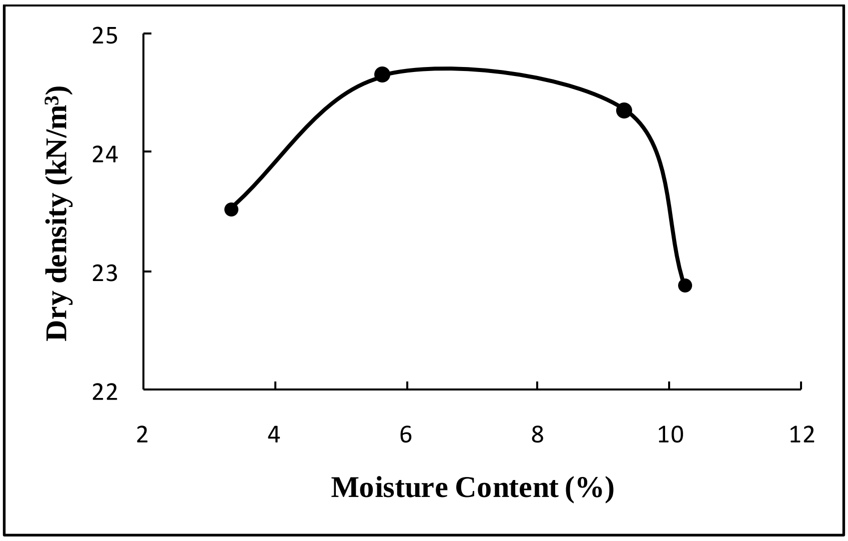


Figure 4.6: Dry density vs. moisture content (60% copper slag + 40% soil)

The following table shows the variation of compaction characteristics viz. MDD and OMC with change in percentage copper slag in soil.

Table 4.2: Compaction characteristics of various mixes

S.No.	Specimen ID	Max. Dry density (KN/m^3)	Optimum moisture Content(%)
1.	C	18.7	13.82
2.	CS10	19.19	12.62
3.	CS20	21.57	11.88
4.	CS30	21.34	11.34
5.	CS40	21.756	10.36
6.	CS50	23.786	6.89
7.	CS60	24.65	6.25

Fig. 4.7 below shows the variation of optimum moisture content with change in copper slag proportion in the mix. The point to be noted in the graph below is that the maximum rate of

decrease in moisture content came out to be 33.49% , this occurs when 50% of the copper slag is added in the soil.

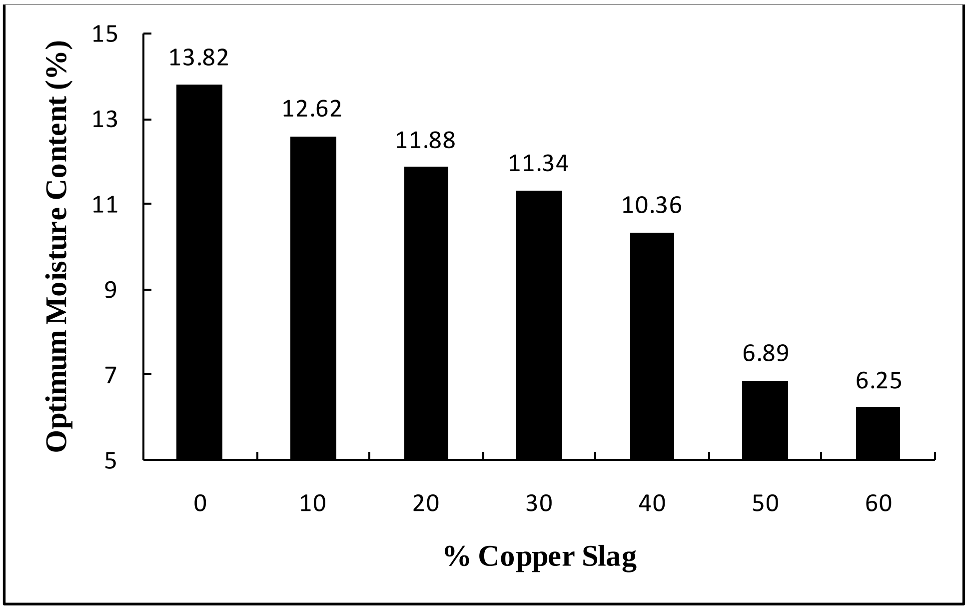


Figure 4.7: Variation of optimum moisture content with % copper slag

Fig. 4.8 depicts the variation of maximum dry density with change in percentage copper slag in the mix. The major rate of increase in the maximum dry density is found to be when 20% of copper slag is mixed in the soil and it is calculated to be 12.94%.

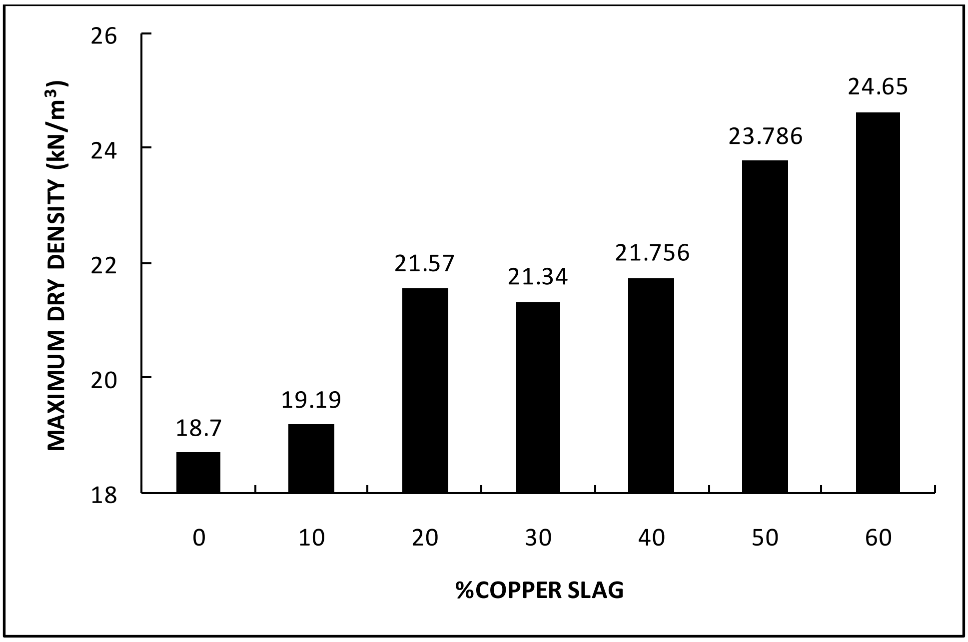


Figure 4.8: Variation of maximum dry density with % copper slag

From the table below it is clear that the maximum dry density is linearly increasing with the increase in the copper slag proportion in the mix and similarly the OMC is linearly decreasing. The maximum percentage decrease in optimum moisture content is reported to be 54.77% and maximum percentage increase in MDD is 31.82% at 60% copper slag

Table 4.3 : Percentage change in OMC and MDD w.r.t the unblended soil

S.no.	Specimen ID	%Increase in MDD	%Decrease in OMC
1.	C	-	-
2.	CS10	2.62	8.68
3.	CS20	15.34	14.03
4.	CS30	14.12	17.94
5.	CS40	16.34	25.04
6.	CS50	27.19	50.14
7.	CS60	31.82	54.77

4.3 EFFECT OF COPPER SLAG ON CALIFORNIA BEARING RATIO(4 DAYS SOAKED)

The California bearing ratio tests were performed according to IS-2720-part-16-1979. It was done for soaked conditions (4 days)

Fig. 4.10 gives the load vs. penetration curve for unblended soil. The CBR value determined from this test was 3.41%.

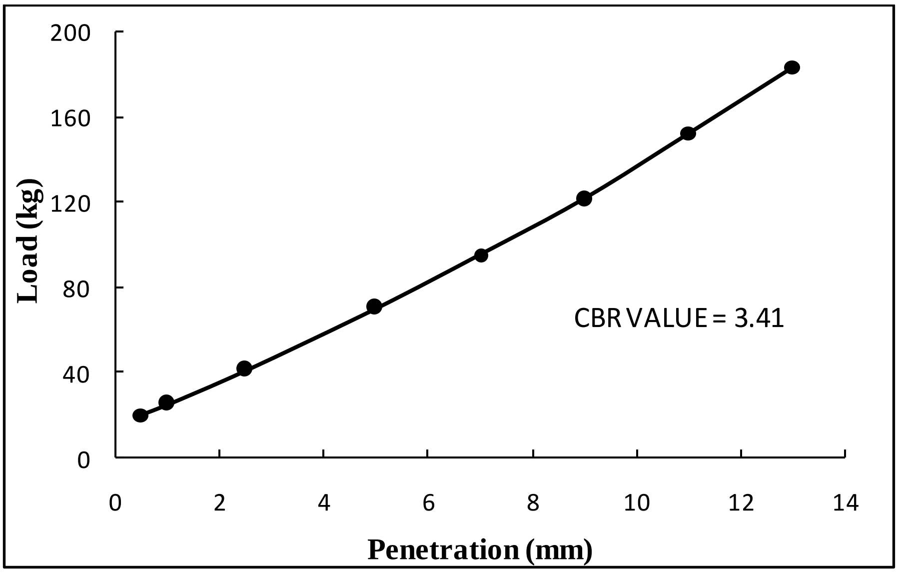


Figure 4.9: Load vs. penetration curve (100% soil)

According to AC 150/5320-6F, if the CBR strength of the subgrade is less than 5%, then it needs to be stabilised either chemically, mechanically or by the replacement of subgrade material. Therefore, copper slag is blended in the soil in various proportions to fulfil the minimum requirement of subgrade CBR.

Fig. 4.11 depicts the load vs. penetration curve for 50% of copper slag in soil. The CBR value in this test came out to be 11.1%.

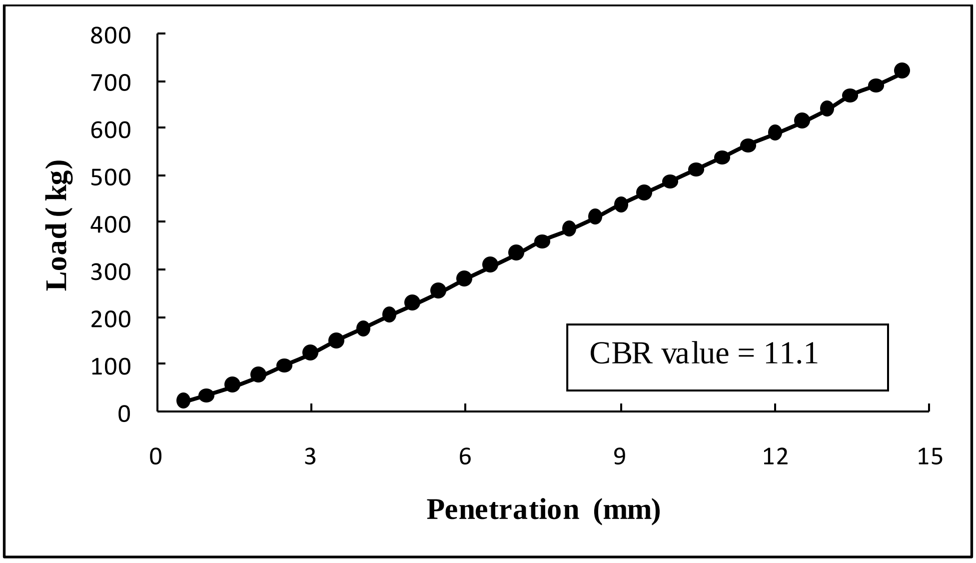


Figure 4.11 : Load vs. penetration curve (50% copper slag + 50% soil)

Fig. 4.12 depicts the load vs. penetration curve for 60% copper slag in the soil and the CBR value came out to be 21.02%.

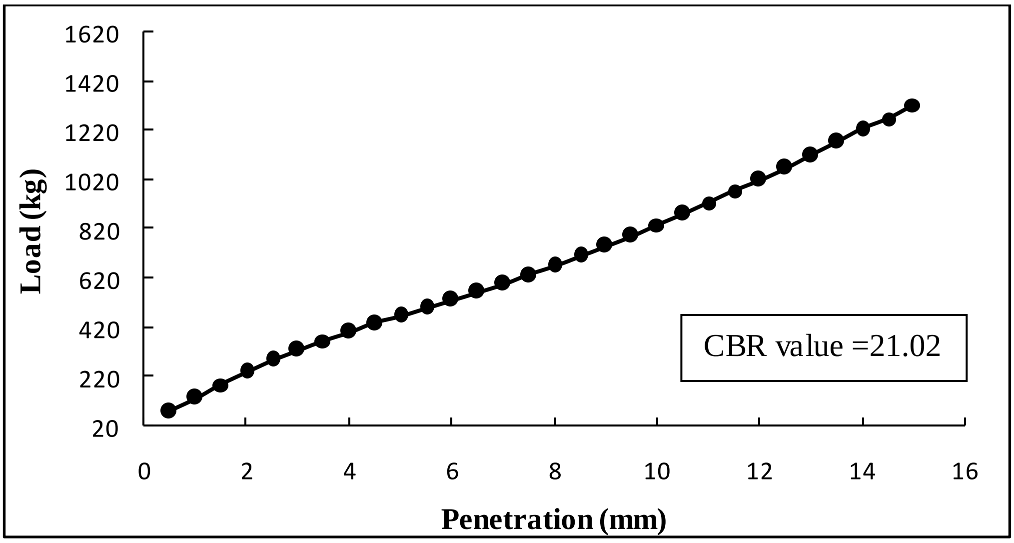


Figure 4.12: Load vs. penetration curve (60% copper slag)

Fig. 4.13 depicts the variation in CBR value with the percentage copper slag. In the graph , it can be observed that the CBR value is linearly increasing with the addition of copper slag in the soil.

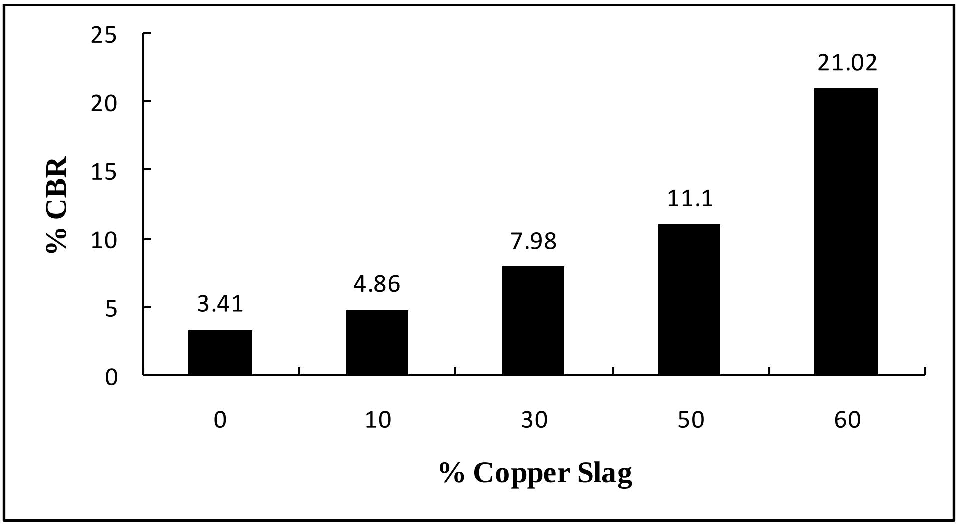


Figure 4.13: CBR vs. % Copper slag

There is a percentage increase of 516.42 % in the CBR value from that of unblended soil to when there is 60% copper slag mixed the soil. The change in CBR value can be attributed to the fact that due to the improvement in geotechnical properties of the soil like plasticity of the soil, increase in dry density of the soil and reduction in moisture content of the soil, the soil has increased load bearing capacity which shows up in the increased CBR values.

4.3.1 Bearing Ratio Index (BRI)

Bearing ratio index is a dimensionless property which can be defined as the ratio of CBR value of reinforced material (CBR_r) to the CBR value of unreinforced material (CBR_u). The BRI value for different mixes are given below in table.

Table 4.4 : BRI for different mixes

S.no.	Specimen ID	BRI
1.	C	3.41/3.41= 1
2.	CS10	4.86/3.41= 1.425
3.	CS30	7.98/3.41= 2.34
4.	CS50	11.1/3.41= 3.255
5.	CS60	21.02/3.41= 6.164

BRI value has increased from 1 for unblended soil to 6.164 for 60% copper slag in the mix.

CHAPTER - 5

FLEXIBLE RUNWAY PAVEMENT DESIGN AS PER AC 150/5320-6F

5.1 GENERAL

The guidance provided by AC 150/5320 - 6F is based on layered elastic theory for the design of flexible pavement. Here a software has been developed by FAA called as FAARFEILD (FAA Rigid and Flexible Iterative Elastic layer Design). Due to the fact that FAARFEILD is used for all pavement designs, there is no differentiation between pavement design for light aircraft and that for aircraft greater than 30,000 pounds. This chapter describes the mechanistic-empirical pavement design procedures which have implementation in FAARFEILD. This program uses three dimensional finite element based design and layered elastic method. For the design of flexible pavement, maximum horizontal strain at the bottom of all asphalt layers and maximum vertical strain at the top of the subgrade are used as the predictors of pavement structural life. Basically in FAARFEILD, thickness required for each layer of pavement can be calculated which will be giving support to a given traffic mix of airplane for some structural design life of the pavement for a given subgrade.

5.2 MATERIAL SPECIFICATIONS

5.2.1 Subgrade (Local soil stabilized with copper slag)

According to AC 150/5320-6F if the mean strength of subgrade is lower than a 7500 psi modulus i.e, CBR of 5%, then it is necessary to improve the subgrade. Whether it is by chemical method , mechanical method or by replacement with the suitable subgrade material or if the CBR is less than 3 i.e. the design modulus is lower than 4500 psi or when the conditions like poor drainage, frost, adverse drainage for surface is there or there is a need for a stable working platform then also the subgrade stabilisation is considered. More often than not it is beneficial to stabilize the subgrade so as to create a stable platform for construction working. A consultation from a geotechnical engineer should always be taken so that long term strength can be achieved with stabilised layers. It is generally recommended that the layer which is stabilised should be 12 inches or 300 mm or as recommended by the geotechnical engineer. If a layer of stabilised material is included during the design of the pavement then it will be essential to model this layer as a user defined layer while performing the structural design of pavement in FAARFEILD.

5.2.2 Subbase (Item: P-209 crushed aggregate)

The coarse aggregate portion in this coarse should retain on 4.74 mm sieve and larger and should not contain flat or elongated pieces more than 15 % by weight. It should contain at least 90% particles by weight with atleast two fractured faces and 100% particles with at least one fractured face.

The percentage of wear in this course should not be greater than 35% if tested according to the ASTM C 131. According to ASTM C 88, the sodium sulphate soundness should not exceed 12%. According to ASTM D 4318, the fraction of material passing through 0.42 mm sieve shall have a liquid limit less than 25 and its plasticity index should be less than 4. According to ASTM D 2419, fine aggregate used in this course should have a minimum sand equivalent value of 35. the fraction of final mixture which passes through 0.075 mm should not exceed 30 % of the fraction which passes through 0.6 mm sieve.

Table 5.1: Gradation requirements of P-209 crushed aggregate.

Sieve size	**Design range (% by weight)**	**Job mix tolerances %**
50 mm	100 mm	0
37 mm	95 - 100mm	+/- 5
25 mm	70-95 mm	+/- 8
19 mm	55 - 85 mm	+/- 8
4.75 mm	30 - 60 mm	+/- 8
0.6 mm	12-30mm	+/- 5
0.075 mm	0-8	+/- 3

For levelling courses finer gradation may be utilised. The minimum thickness required for a levelling course shall be 38 mm. The material should not be placed on frozen subgrade . Two or more layers could be provided to the course if its thickness gets more than 150 mm. During placing the moisture content of the material should not be more than 2% point above the moisture content determined by ASTM.

5.2.3 Base (Item: P- 403)

This item consist of a mineral aggregate and asphalt binder specifications of P-403 is similar to P- 401 with some exceptions. Following are given those exceptions:

1. Marshall design criteria for stability, air voids and flow are not as stringent.
2. There is no evaluation on the basis of flow and stability from plant material. It is based on thickness, smoothness , grade , mat and joint density.SSS
3. Density is based on a straight acceptance limit i.e, 96 % for mat density and 94 % for joint density. PWL is not used.

5.2.4 Surface course (Item: P-401 Hot mix asphalt)

This specification is to be used for the surface course for pavements which are subject to the aircraft loadings of gross weights more than 12,500 pounds.

Coarse aggregates - If the gross load on the pavement is 60,000 pounds or more, two fractured faces particles should be 75 % and 85% for one face fractured. If the gross load is less than 60,000 , then two fractured faces should be 50 % by weight and 65 % for one fractured face.

Fine aggregate - The plasticity index for fine aggregate should not be more than 6 and liquid limit should not be more than 25% if tested according to ASTM D 4318. If sodium sulphate is used than the soundness loss should not exceed 10 % or 15 % if magnesium sulphate is used.

5.3 PAVEMENT LIFE

The structural life of the pavement is referred to as the design life. This can be defined as to how many load cycles a pavement will carry before failing. The factors which determine the thickness of the pavement are : the impact on environment, magnitude and character of airplane, distribution and volume of traffic, etc. Also some other factors are responsible like airplane mix, material quality routine pavement maintenance.

5.4 CUMULATIVE DAMAGE FACTOR (CDF)

FAARFEILD works on the concept of cumulative damage factor in which the total cumulative damage from all aircrafts in the traffic mix is considered . The effects of the damage caused by all airports are summed under Miner's law.The design considerations are said to be satisfied when the value of cumulative damage factor equals to 1.So CDF represents the amount of structural fatigue life which has been used up. If we are doing a new pavement design , the adjustment in the pavement structure is made by the software until the point when CDF equals to 1. Mathematically CDF can be expressed as following :

$$CDF = \frac{No. of\ applied\ load\ repetitions}{No. of\ allowable\ repetions\ to\ failure} \qquad \text{..................eqn.5.1}$$

or

$$CDF = \frac{Applied\ coverages}{Coverages\ to\ failure} \qquad \text{....................eqn.5.2}$$

In this software , CDF is calculated for 10 inch wide strip along pavement and having a total width of 820 inches. It is assumed that 75 percent of passes fall within the wander width of 70 inches and P/C ratio is computed assuming. The maximum value for CDF among all 82 strips is considered for the design.

FAARFEILD consists of five main forms as shown in figure below :

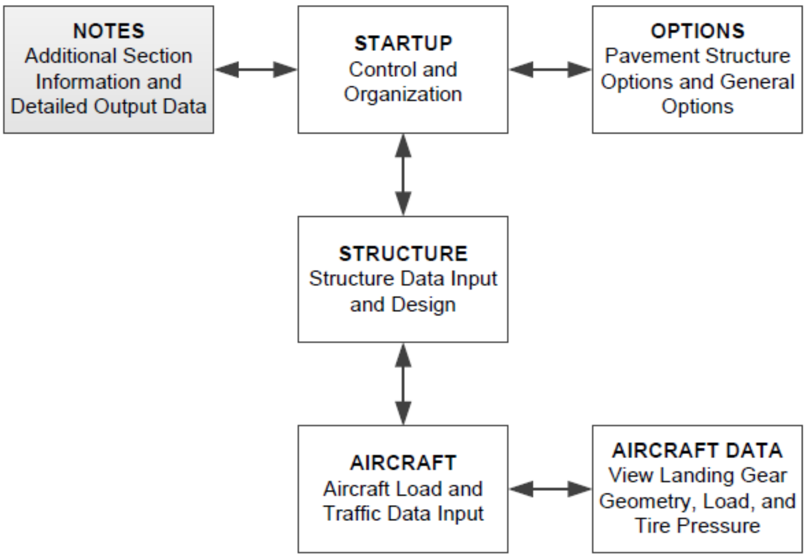


Figure 5.1: Overview of FAARFEILD program.

5.5 FAARFEILD PAVEMENT DESIGN PROCESS

This is an iterative process. Following are the basic design steps :

Step 1: Using Start Up, first of all create new job and add the basic sections to it for analyzing

Step 2: Using the option of Structure, modify the pavement structure which is to be analyzed

Step 3: Using Airplane option, add airplane load

Step 4: Return to Structure and click on the option of Design pavement structure.

Step 5: Adjust the thickness of layer, Change the types of layer and repeat step 4

Step 6: Select the option of Life/ Compaction and print out design report

Step 7: Return to StartUp and view pavement design report.

Step 8 : Print pavement design report and get it included with the engineer's report

5.6 AIRCRAFT TRAFFIC CONSIDERATIONS

5.6.1 Load

It is assumed that 95% of the gross weight is carried by the main landing gears and 5 percent is carried by the nose gear. Using the maximum take off weight provides a conservative design which allows the changes in operational use and traffic and helpful where traffic is operated at less than maximum load.

5.6.2 Tire Pressure

Tire pressure depends on the gear configuration, tire size and gross weight . Gross weight is directly proportional to the tire pressure. Tire pressure influences the strains in the asphalt surface layer instead of at the subgrade. If flexible pavements constructed have high stability asphalt then tire pressures upto 254 psi i.e, 1.75 MPa are accomodated.

5.6.3 Aircraft traffic volume

Generally pavement must be decided for regular use and regular means atleast 250 annual departures which means 500 operations. Due to the fact that aircraft have a heavier weight when they depart as compared to when they arrive, it happens that aircraft pavements are designed according to the aircraft departures only. FAARFEILD enables us to calculate total number of departures for a given design life period.

5.7 PASS-TO-COVERAGE RATIO

An aircraft never moves along a perfectly straight path and this lateral movement of airplane of it been wandering can be explained statistically by a normal distribution. So when an aircraft goes along a runway, it takes several trips and passes to receive a full load application. So pass to coverage ratio can be defined as the ratio of number of passes which are required for the application of one full load to unit area of pavement. The number of coverages made is derived mathematically internally in FAARFEILD .That one coverage can be defined as that when a unit area of pavement have the maximum response i.e, strain in the case of flexible pavement. In the case of flexible pavements, coverages can be defined as the measure of the total repetitions of the maximum strain happened at the top of subgrade.

The subgrade thickness is taken as infinite and its characterisation is done by either CBR value or elastic modulus. FAARFEILD uses following relationship to compute design modulus of elasticity:

$$E = 10 \times CBR \text{ (E in MPa)} \qquad \text{.........................eqn.5.3}$$

5.8 AIRPLANE INFORMATION

Following is the airplane information in which the gross weight of aircrafts, annual departures, % annual growth are detailed. From the table given below it can be seen that a mix of different types of aircrafts were taken like single wheel loads, dual tandem , boeing , airbus, douglas and other type of miscellaneous aircrafts . In this way a total of 20 aircrafts were considered :

Table 5.2 : Airplane information

No.	Name	Gross Wt. (lbs)	Annual departures	%Annual growth
1.	S-60	60,000	1,200	1.00
2.	S-75	75,000	1,250	1.60
3.	D-75	75,000	1,700	1.50
4.	D-100	100,000	1,650	0.80
5.	D-150	150,000	2,900	1.40
6.	2D-150	200,000	1,200	0.45
7.	2D-200	300,000	2,000	0.75
8.	2D-300	300,000	1,400	1.45
9.	2D-400	400,000	1,200	1.50
10.	A300-B2 std	315,041	1,600	1.50
11.	A300-B4 std	365,747	1,250	0.65
12.	A300-600std	170,000	1,300	1.20
13.	B727-100C Alternate	361,000	2,500	0.85
14.	B767-200	109,000	1,650	0.60
15.	DC9-32	122,000	1,200	1.40
16.	DC9-51	122,000	1,300	1.20
17.	DC10-10	458,000	1,270	0.75
18.	L-1011	498,000	1,200	0.60
19.	C-123	60,000	2,600	1.80
20.	C-130	155,000	1,200	0.70

5.9 PAVEMENT LAYERS THICKNESS

The pavement layers thickness for different proportions of CBR is calculated by the use of computer program called FAARFEILD. These layers thickness are determined for a design life of 20 years.

It can be seen from the fig. 5.2 below, these are the thickness of each layer as determined by FAARFEILD at the soaked CBR of 3.4% when there is no copper slag in the soil and the soil is used as it is. The total thickness to the top of the subgrade is determined to be 45 inches which consists of subbase thickness as 36 inches, base thickness as 5 inches and surface course thickness as 4 inches.

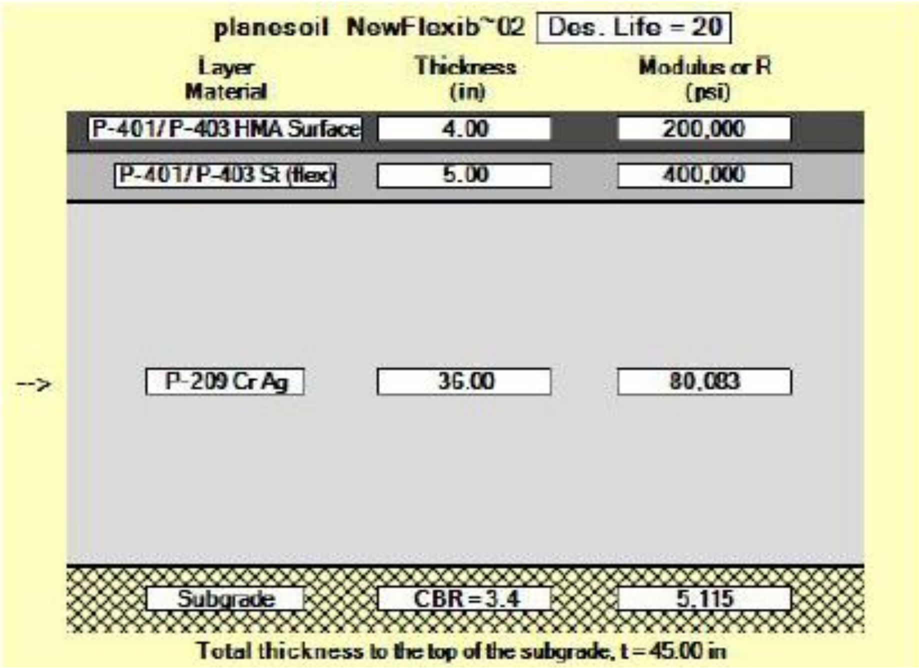


Figure 5.2 :Pavement layers thickness for subgrade with no copper slag

Now in fig. 5.3, the pavement layers thickness is shown for a soaked CBR of 4.9% and this is when 10 % of copper slag is mixed. The total thickness to the top of the subgrade came out to be 38.77 inches which consists of 36 inches of subbase and again base and surface course have thickness same as 5 inches and 4 inches like before. So it can be observed that there is a decrease in total pavement thickness and it has decreased by 6.23 inches. This is a percentage decrease of 13.84 %.

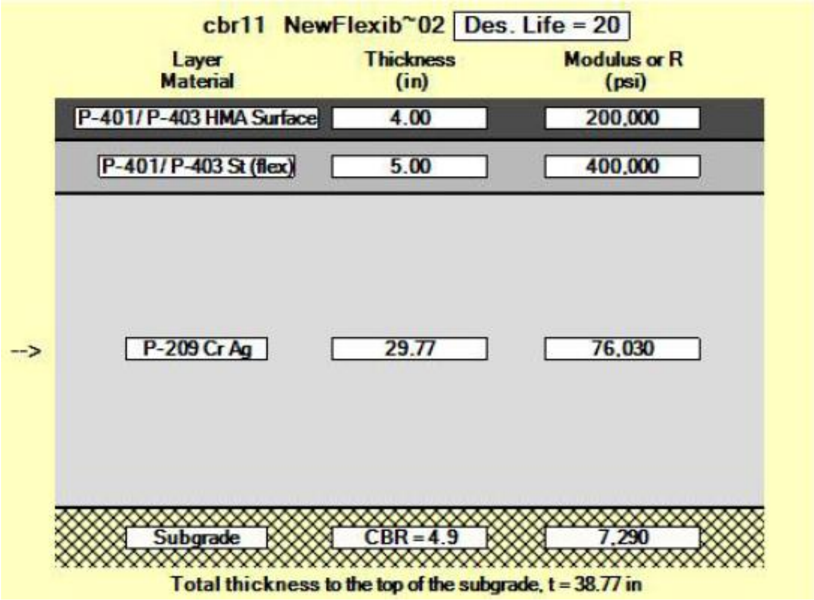


Figure 5.3:Pavement thickness layer when 10% copper slag is mixed

In fig. 5.4, the pavement layers thickness is calculated at a soaked CBR of 8% and that is when 30% of copper slag is added in the soil. The total thickness to the top of the subgrade came out to be 29.51 inches which again consists of the same thicknesses of surface course and base course as 4 inches and 5 inches respectively and the subbase thickness determined is 20.51 inches. So there is a further decrease of 23.88% in the pavement thickness when compared to the soil with 10% copper slag. However the total percentage decrease in pavement thickness when compared with unblended soil came out to be 34.42% which is an impressive percentage decrease.

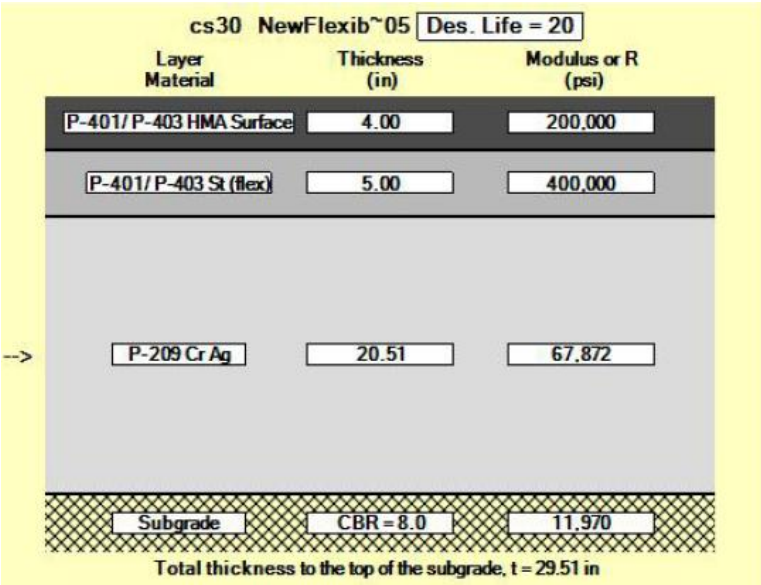


Figure 5.4: Pavement thickness layer when 30% copper slag is provided

Fig.5.5 shows us the pavement layers thickness at the subgrade CBR of 11.1% when 50% of copper slag is mixed in the soil. Here the total thickness to the top of the subgrade came out to be 23.73 inches which consists of 14.73 inches of subbase layer with base course and wearing course as usual 5 inches and 4 inches respectively. The percentage decrease in the pavement thickness as compared to that when soil is mixed with 30% of copper slag is 19.58% whereas the decrease in the pavement thickness as compared with that of unblended soil is found to be of 21.27 inches which is a percentage decrease of 47.26%.

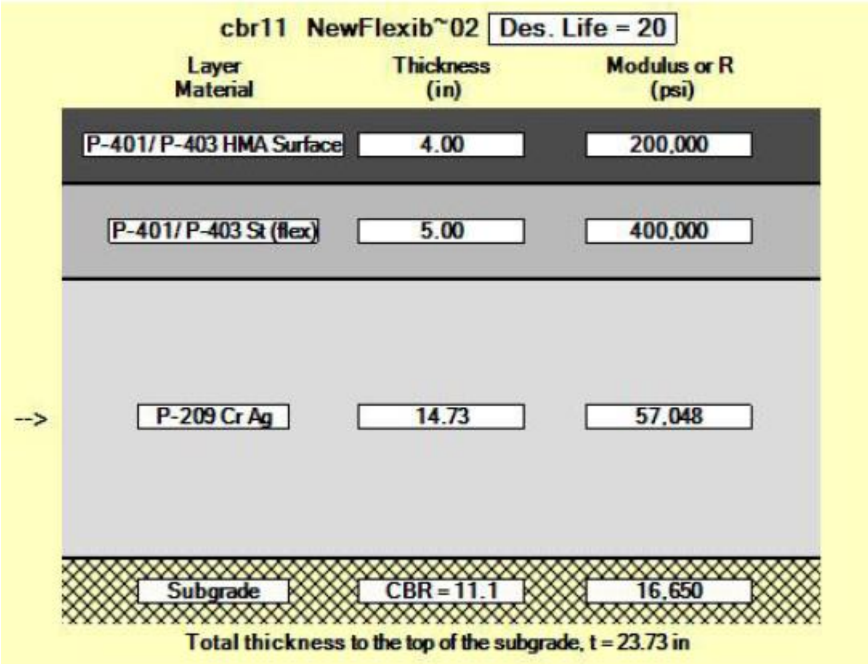


Figure 5.5: Pavement thickness layers when 50% copper slag is mixed

Fig. 5.6 gives us the pavement layers thickness at a subgrade CBR of 22% when 60% of copper slag is mixed in the soil. The total thickness to the top of the subgrade came out to be 15.11 inches only out of which thickness of the subbase is 6.11 inches and the wearing course and base course thickness are according to the codal provisions and a provided a minimum value of 5 inches and 4 inches respectively. The decrease in the thickness as compared to the previous case when 50% copper slag was there, came out to be 8.62 inches and the total decrease in the pavement thickness when compared with the unblended soil came out to be 29.89 inches which gives a percentage decrease of 66.42% which is a huge percentage decrease.

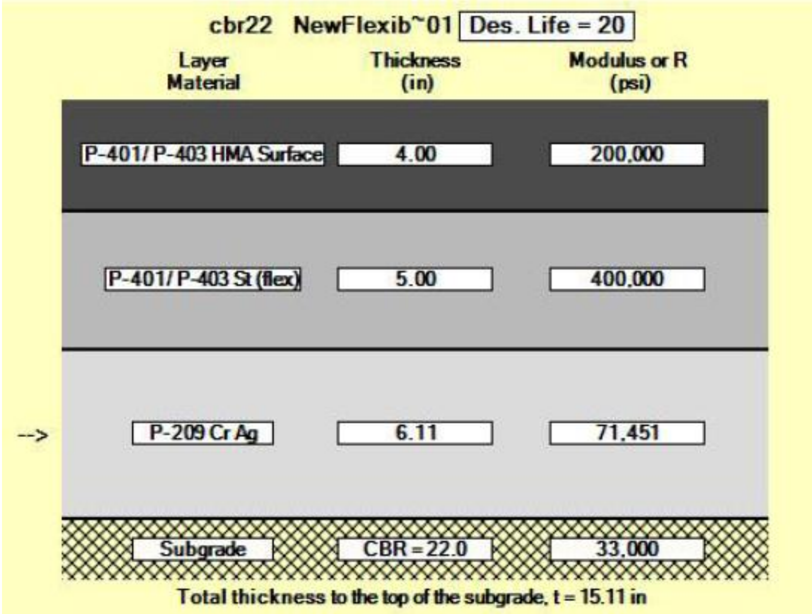


Figure 5.6: Pavement layers thickness when 60% copper slag is mixed

Following table gives us the variation of pavement thickness w.r.t the proportion of copper slag in the mix and further the percentage decrease in these thicknesses is calculated . As we can observe from the table that there is a reduction of 66.42% in thickness of the pavement when the proportion of copper slag in the soil is 60% and at this mix the thickness of the pavement has reduced to 15.11 inches only.

Table 5.3: Pavement layers thickness at different subgrade mixes

S.no.	**% Copper slag**	**Soaked CBR (4 days)**	**Total Pavement thickness to the top of the subgrade**	**% Decrease in pavement thickness w.r.t the unblended soil**
1.	0%	3.4	45 inches	-
2.	10%	4.9	38.77 inches	13.84%
3.	30%	8.0	29.51 inches	15.49%
4.	50%	11.1	23.73 inches	47.26%
5.	60%	21	15.11 inches	66.42%

As we can see from the table 5.1 above that with the increase in the proportion of the copper slag in the subgrade mix, the pavement thickness continues to reduce linearly and considerably. This has happened due to the fact that as we are adding more and more copper slag to the soil, the compaction of the subgrade is happening more effectively with an increase in maximum dry density and decrease in the optimum moisture contents as discussed in chapter 4 of this thesis. Therefore this compaction has led to the greater CBR values of the subgrade with an increase in copper slag proportion which has led to the more strengthened pavement layers without the need of increasing their thicknesses.

From the above pavement layers thickness diagrams it is clear that the surface course and the base course are having same minimum thickness of 4 inches and 5 inches respectively even when the proportion of copper slag is changed. Only the thickness of sub base layer is changing due to which there is a change in the total thickness. Below is the graph given to depict the variation of sub base thickness with change in copper slag proportion in the mix.

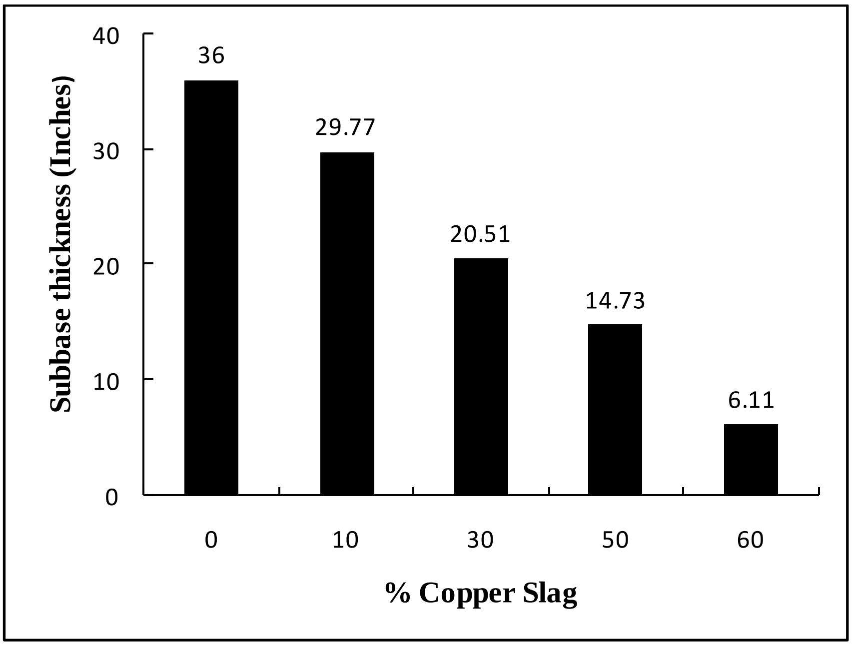


Figure 5.7: Variation of sub base thickness with % copper slag

5.10 SUBGRADE CDF GRAPHS

FAARFEILD also provided the cumulative damage factor graphs for different subgrade mixes. From these graphs it can be known as to which aircraft has the maximum contribution of cumulative damage factor on the subgrade.

In fig. 5.7, it is shown that the aircraft 2D-400 has the maximum contribution of CDF and that is equal to 0.91.The other aircrafts which contributes negligibly to the CDF are A-300B4std., A300-600std. and L-1011 with CDF contributions as 0.01, 0.05 and 0.03 respectively. All the other remaining aircrafts do not have any effect on subgrade CDF.All these together sum up to CDF =1.

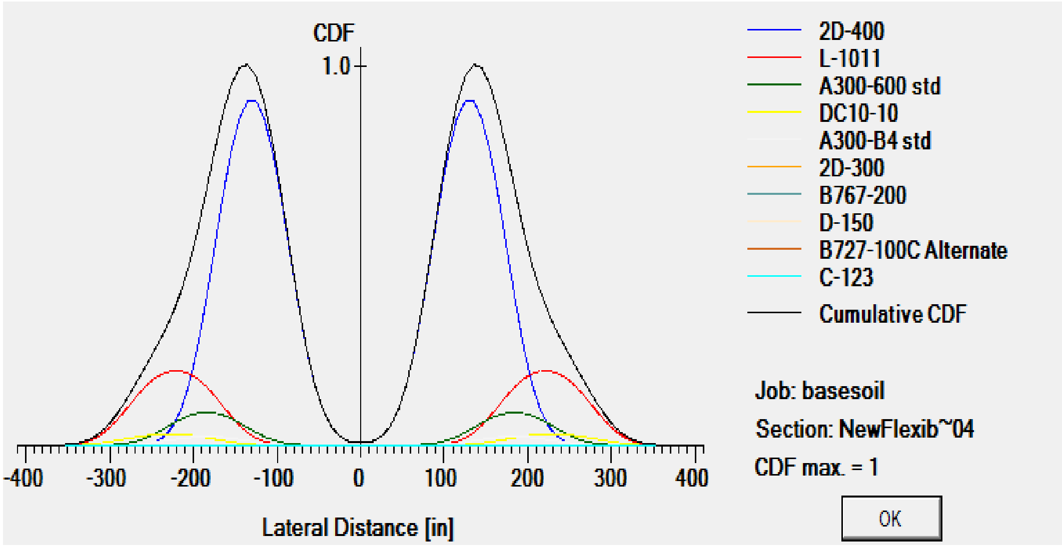


Figure 5.8 :CDF graph for soil with no copper slag , CBR 3.4

In fig. 5.8, CDF graph for a mix of 10% copper slag and 90% soil is given. From this graph it can be observed that maximum CDF contribution is due to the 2D-400 aircraft and it is 0.96. Other aircrafts which negligibly contribute are A300-B4 std.,A300-600 std., and L-1011 having very small contributions as 0.01,0.03 and 0.01 respectively.

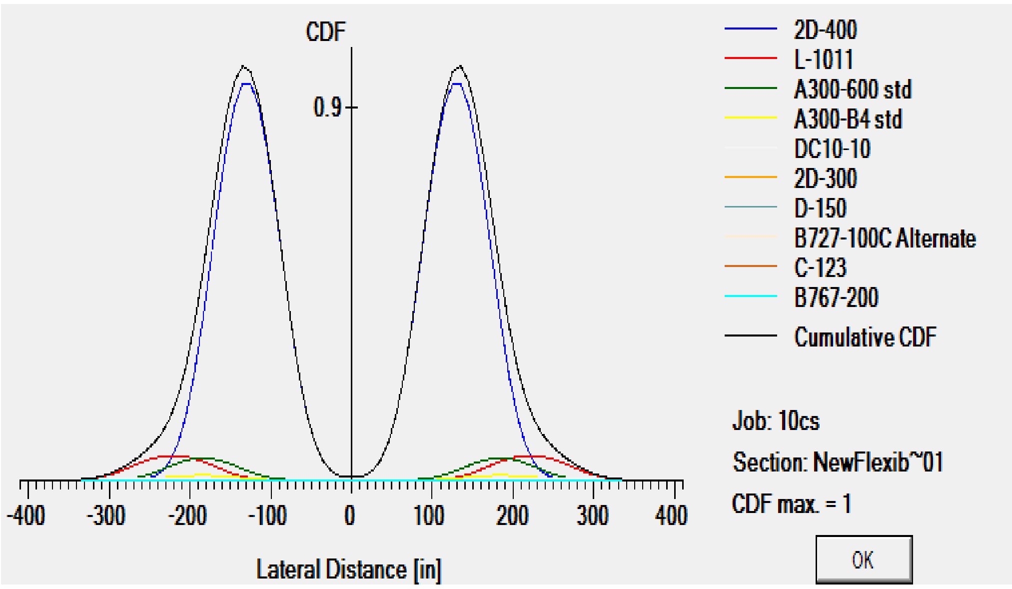


Figure 5.9: CDF graph for 10% copper slag + 90% soil , CBR 4.9

Following is the CDF graph for subgrade having a mix of 30% copper slag and 70% soil. This graph depicts that the CDF contribution by 2D-400 is very large and is equal to 0.98.The contribution of other aircrafts like A300-600std. is near to zero and is equal to 0.01.

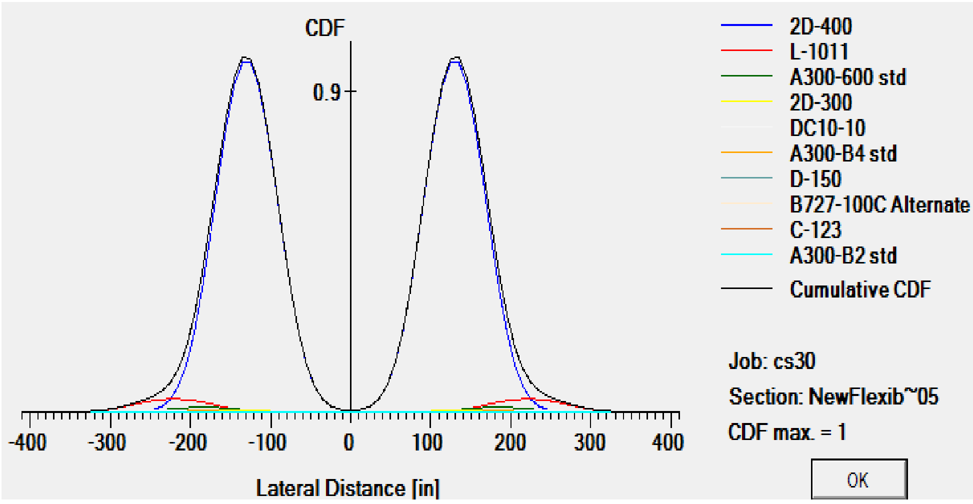


Figure 5.10: CDF graph for 30% copper slag + 70% soil, CBR 7.98

In fig. 5.10, the CDF contribution by the aircraft 2D-400 is a little bit decreased as compared to previous cases and is equal to 0.94 whereas contribution by the aircraft L-1011 is a little more than before and is equal to 0.04. However the contribution by A300-600std. remains negligible and equal to 0.01.

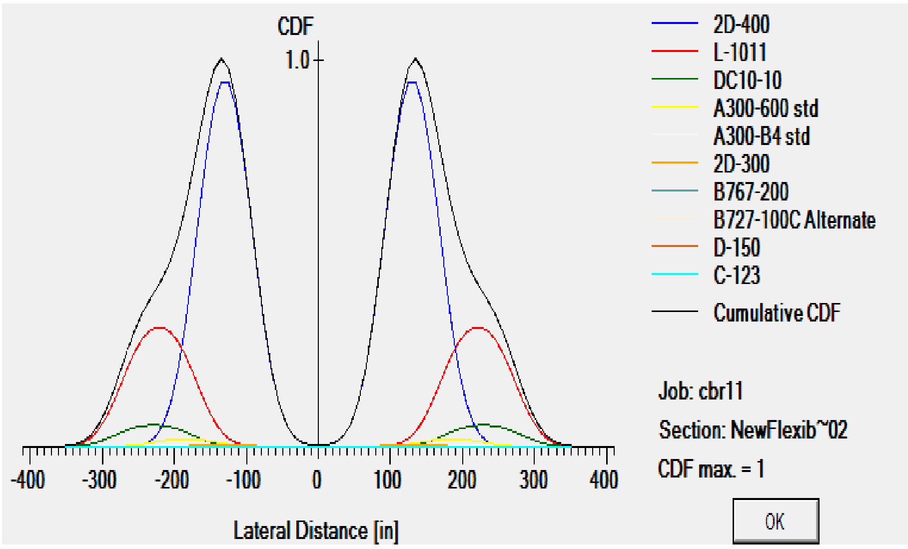


Figure 5.11: CDF graph for 50% copper slag + 50% soil, CBR 11

In fig.5.11, the CDF graph for the subgrade is shown when the subgrade mix consists of 60% of copper slag and 40% of soil. In this graph the CBR of the subgrade is 22 and the maximum CDF contribution is done by L-1011 which is 0.69. The other smaller contributions are by DC10-10 and A300-600std. which are 0.29 and 0.01 respectively.

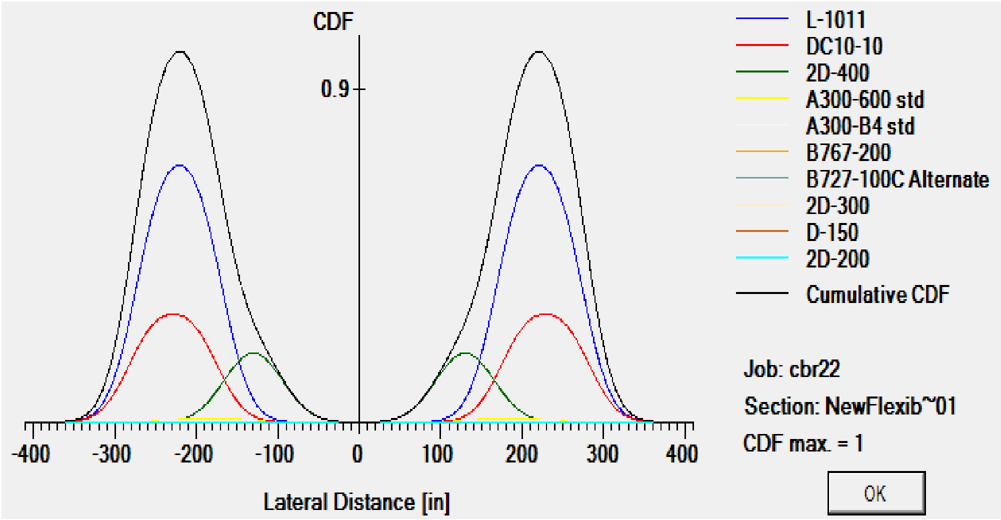


Figure 5.12: CDF graph for 60% copper slag + 40% soil , CBR 21

5.11 ASPHALT CDF

FAARFEILD also provides the values of asphalt CDF each time the pavement layer thickness is designed. Following table depicts the variation of asphalt CDF with the varying CBR and copper slag - soil mix. From table 5.2 it can be observed that the asphalt CDF is increasing with the increase in the CBR value of subgrade and with the increase in the copper slag proportion upto 50% of copper slag in the mix.

Table 5.4: Variation of asphalt CDF with CBR

S.no	% Copper slag	CBR	Asphalt CDF
1.	0%	3.4	0.0127
2.	10%	4.9	0.0227
3.	30%	8.0	0.1067
4.	50%	11.1	0.4691
5.	60%	22	0.3503

Mainly there are two failure modes while designing flexible pavement. One is the vertical strain in subgrade and other is the horizontal strain in the asphaltic layer. However, by default, FAARFEILD calculates the thickness of the pavement only by considering the strain for subgrade. But user also has the option of considering the asphalt strains by clicking on the' HMA CDF' checkbox in options screen.

Fig. 5.13 depicts the variation of asphalt CDF with change in the percentage of copper slag in the mix.

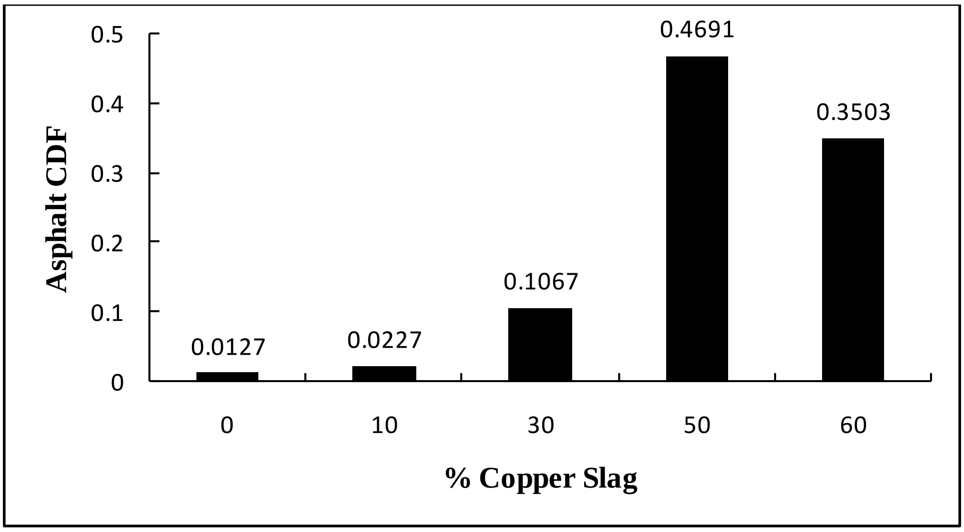


Figure 5.13 : Variation of asphalt CDF with % copper slag

From the graph above it is clear that the cumulative damage factor increases up to 50% of the copper slag in the mix and thereafter it decreases for 60% copper slag. So the horizontal asphalt strain is maximum when 50% of copper slag is added in the mix.

CHAPTER - 6

CONCLUSION

The feasibility of stabilising soil with copper slag was investigated in this study. Granular size copper slag was randomly mixed with locally available soil and tested to determine CBR values. Design of flexible pavement for airport was done using the computer program FAARFEILD. Based on the results the following conclusions can be drawn :

1. Addition of copper slag to local soil has caused the decrease in the plasticity index of the soil. The plasticity index of the soil has reduced from 8.5% for virgin soil to 1.585% for 60CS. This has led to the change in classification of soil from CL to sandy soil.
2. Compaction properties of the soil were improved as maximum dry density witnessed a percentage increase of 31.82% and there was decrease of 54.77% in the optimum moisture content at CS60 when compared to the base soil.
3. Addition of copper slag to local soil increases the CBR value. The CBR value increased from 3.41% for virgin soil to 21.02% for CS60. Total percentage increase in CBR was observed to be 516.42%.
4. It was observed that there was decrease in pavement crust thickness with the addition of copper slag in the subgrade soil. A decrease of 66.42% in pavement crust thickness was observed at CS60.
5. Pavement construction cost can be saved since the thickness has reduced considerably due to the addition of copper slag.

Future scope of work

By using copper slag in the subgrade, a trial airport pavement section can be constructed and the performance of these runway pavements can be evaluated under the repetitive loading.

REFERENCES

1. AC 150/5320 -6F, Airport Pavement design and evaluations,10 Nov. 2016

2. Baraskar T, Ahirwar S.K. (2014).Study on California Bearing ratio of Black Cotton soil using waste copper slag, International Journal of Engineering Sciences and Management, Kumrawat4(3).152- 163.

3. Chandrashekhar J, Chokshi A.T, Chauhan V.D (2015). A review on utilisation of waste material copper slag in geotechnical applications. IJIRST –International Journal for Innovative Research in Science &Technology.Volume 1 .Issue 12 .45-53.

4. Gupta R.C, Thomas B.S, Gupta.P, Rajan.L, Thagriya.D (2012). An experimental study of clayey soil stabilised by copper slag.International Journal of Structural and Civil engineering Research.Vol. 1.No. 1.97-102.3

5. IS 2720-Part - I (2006) Grain size analysis, Bureau of Indian standard , New Delhi , India.

6. IS 2720- Part IV (1985) Determination of Liquid limit and Plastic limit, Bureau of Indian standard , New Delhi , India

7. IS 2720 - Part VII (1995) Determination of water content, Bureau of Indian standard , New Delhi , India.

8. IRC : 37- 2012 " Guidelines for design of flexible pavements "

9. Kavisri M, Senthilkumar P, Gurukumar M.S, Pushparaj K.J (2017). Experimental study on effects of clayey soil using copper slag and GGBS .Rasayan journal,Vol.11. No.1. 111-117

10. Kumar R.P, Kumar P.S.P, Maheswari.G (2017). Laboratory study of Black cotton soil blended with Copper Slag and Fly ash .International Journal of innovative Research in Science , Engineering and Technology.Vol.6. Issue 2. 2347 - 2352

11. Mohan Chand.A, Ramesh babu .V, Ramesh babu .B, Nivedhita K(2017). Behaviour of black cotton soil with addition of copper slag and steel slag.International research journal of Engineering and Technology. Volume : 04.Issue : 01.235-245

12. Mohanraj P, Muthupandi G, Kumar N.K (2017).Experimental study on stabilisation of soil using copper slag and lime mortar. South Asian Journal of Engineering and Technology.Vol.3.No.7.67-79

13. MORTH "specifications for road and bridge works "

14. Nawagamuwa U.P., Madushanka H.K.P. (2017). Ground improvement with waste copper slag. Katubedda. Morutawa.Srilanka.456-471

15. Patel P, Beladiya R, Mistry D, Desai .H, Limbasiya P. (2017).Improvement of index properties of expansive soil by using copper slag.International Journal of advanced Research in Engieering , Science and management.234-245.

16. Qureshi A., Mistry M.H. , Patel D.V. (2015). Improvement in soil properties of expansion soil by using copper slag.International Journal of advance Research in Engineering . Science and technology .Volume 2.Issue 7 .175-181

17. Ravi E, Udhayasakthi R, Vadivel T.S (2016).Enhancing the clay soil characteristics using copper slag stabilisation. Journal of advances in chemistry.Volume 12.Number 26.176-189

18. Reddy P.V.S, Nanthakumar S (2016). A study on the effect of copper slag and lime treated clay.International Conference on Engineering Innovations and solutions.231-240

19. Venkati B., Nagaraju A. (2016). California bearing ratio of Black cotton soil using waste copper slag. International Journal of research. Volume 03. Issue 13.121-131