CHAPTER - 4

APPLICATIONS IN CIVIL ENGINEERING AND ECONOMIC VIABILITY

Any stabilized waste material can be used as a construction material in Civil Engineering only when the end product satisfies the following characteristics:

- ✓ Strength characteristics (Compressive and Tensile)
- ✓ Their Durability
- ✓ Immobilization or stable characteristics (Leachate)

As concerning the experimental results of current study of jarosite (presented in the chapter 3), it is evaluated that, stabilized jarosite have satisfactory strength characteristics (Unconfined compressive strength ≈ 11 Mpa and Split tensile strength ≈ 680 kPa, at 90 days curing with 30% GGBS and 10% Lime), satisfactory durability characteristic (Freeze-thaw, Strength Loss ≈ 14.20% and Weight loss ≈ 6.20% at 30% GGBS-10% Lime blend with 28 days curing period) and acceptable leaching characteristics (Toxic elements are within the permissible limits as the results show that they are either immobilized or show stable characteristics). Also the relationships proposed, between q_u or q_t with various GGBS content (G), lime content (L) and curing period (t) will help the engineer/user to optimum amount of GGBS and lime against targeted compressive or tensile strength of jarosite-GGBS-lime blends. Furthermore, it may be advocated that the tensile strength and unconfined compressive strength of GGBS-lime stabilised jarosite are related, and the ratio q_t/q_u is related by a scalar (0.122) (Eq. 3.12). This scalar is independent of curing period, lime content and GGBS content.

Thus, for an engineer/user, from these dosage methodologies, it is possible that one can target either on tensile strength or on compressive strength to get the desired result.

4.1 Applications in Civil Engineering

After fulfillment of above listed properties, the stabilized product may be used in many applications depending upon their suitability. In the present study of jarosite waste stabilization, the above listed properties are broadly satisfied and hence, the end product can be used in the various applications of civil engineering such as:

- ✓ Foundation material in pavement design,
- ✓ In making unfired bricks or,
- ✓ Filler material in embankment.

4.1.1 Jarosite as a construction material in pavement design

The guidelines of U.S. Army Corp of Engineers manual [93] for minimum requirements of UCS of lime stabilized materials to be used as a sub grade, sub base and base material in the design of flexible as well as rigid pavement is present in Table 4.1.

It is revealed from Table 4.1 that the lime stabilized material should have the satisfactory strength to be used in sub base course or sub base i.e. UCS up to 1725 kPa and 1380 kPa, and in base course up to 5170 kPa and 3450 kPa for flexible and rigid pavement respectively. On a closer look of UCS test results presented in Table 4.1, it is revealed that jarosite blended with lime and GGBS can be used as different component of pavement design depending on their UCS results. For example, jarosite stabilized with 10% lime and 30% GGBS, cured for 90 days curing period has UCS of ~ 11 MPa. Thus, it can be advocated that this blend (30% GGBS-10% lime stabilized jarosite) has the adequate strength to be used as a construction material in design of sub grade, sub base and base course for both types of pavement.

Table 4.1 Minimum unconfined compressive strength for pavement design [93]

Mixtures	UCS at 28 days curing time (kPa)	Minimum unconfined compressive strength (kPa) (U.S. Army Corp United Facilities Criteria) (28 Days Curing)			
		Pavement Types			
		Flexible		Rigid	
		Base course (>5170 kPa)	Sub base course, or subgrade (>1725 kPa)	Base course (>3450 kPa)	Sub base course, or subgrade (>1380 kPa)
J-2.5L	780	×	×	×	×
J-5.0L	1112	×	×	×	×
J-7.5L	1641	×	×	×	✓
J-10L	2490	×	✓	×	✓
J-2.5L-10G	1450	×	×	×	✓
J-5.0L-10G	2122	×	✓	×	✓
J-7.5L-10G	2332	×	✓	×	✓
J-10L-10G	3780	×	✓	✓	✓
J-2.5L-20G	3320	×	✓	×	✓
J-5.0L-20G	4078	×	✓	✓	✓
J-7.5L-20G	4452	×	✓	✓	✓
J-10L-20G	6478	✓	✓	✓	✓
J-2.5L-30G	7645	✓	✓	✓	✓
J-5.0L-30G	8760	✓	✓	✓	✓

J-7.5L-30G	9989	✓	✓	✓	✓
J-10L-30G	11085	✓	✓	✓	✓

4.1.2 Development of solidified, durable and immobilized unfired bricks

As per the process described in IS: 12894:2002 [73], the unfired Jarosite-GGBS-Lime stabilized bricks is constructed at Council of Scientific and Industrial Research - Advanced Material and Processes Research Institute (CSIR-AMPRI), Bhopal, India, during two months project work as a part of this study. The solidified brick was tested for compressive strength after curing (7, 14 and 28 Days curing) and water absorption (24h).

This innovative product (scaled size brick) can be used as a brick in Civil Engineering construction since it fulfils the requirement of compressive strength (> 3.5 MPa) and water absorption limits (< 20%) as per Indian Standards for unfired bricks [73]. The details of brick preparation, testing and test results of brick are kept on hold as a patent has been filed that prohibits disclosure of details.

In this invention, an attempt is made to explore the possibilities for utilization of hazardous jarosite (stabilized with inorganic waste additive such as ground granulated blast furnace slag (iron industry by-product) and small amount of alkali activator such as hydrated lime) for development of durable, solidified/stabilized, immobilized products, which will one hand reduce the contamination of the soil and ground water and on the other hand be economical substitution of conventional constructional materials.

(a)

(b)

(c)

(d)

Figure 4.1 Photographs showing (a) Stabilized jarosite bricks; (b) Bricks before curing; (c) Bricks after curing; (d) Automatic universal testing machine used for compressive strength test

4.2 Economic Viability

Presently, in India, disposal of jarosite is being done in the form of jarofix (jarosite blended with 2% lime + 10% cement). The author make an attempt to compare the cost of jarosite waste stabilized with up to 10% lime and 30% GGBS with that of jarofix using two examples.

4.2.1 Example 1: Cost of construction of an embankment of 1 m^3

The cost of construction of 1 m^3 of embankment is estimated as per the Analysis of Rates of Delhi, Central Public Works Department (CPWD), Govt. of India [94] in terms of Indian rupees (₹). The Table 4.2 illustrates the construction cost comparison for making 1 m^3 embankment.

Table 4.2 Cost estimation of 1 m^3 embankment construction [94]

Particulars	**Cost Estimation (₹) Per Cum of Embankment**	
	J-30% G-10% L	Jarofix (Jarosite-2% Lime-10% Cement)
Materials cost *Jarosite & GGBS both wastes are available for free at Zinc and steel plants respectively.	179.2	822.5
Hauling cost (Including uploading, unloading and stacking) *Assumed hauling distance of jarosite, GGBS, Lime & cement are 30 km for all.	190.02	190.02
Compaction cost including filling, rolling/ramming and watering	125.75	125.75
Total (₹)	**494.97**	**1138.75**

The above financial estimation advocates that the utilization of jarosite treated with GGBS and lime can be reduced by up to **56.53%** of the total cost of construction of 1 cum embankment as compared to the cost of jarofix (jarosite treated with lime and cement jarofix) used by zinc industries.

4.2.2 Example 2: Cost of a standard size brick

A standard size brick (19 x 9 x 9 cm) is casted using stabilized jarosite, and then the cost of one brick is estimated as:

- Cost of 1.0 m^3 stabilized jarosite (30G-10L) is ₹ **494.97**. (Table 4.2)
- Size of brick is 19 × 9 × 9 cm (0.001539 cum), thus the cost for making one brick is ~ ₹ **0.77*** only.
- Cost of a conventional clay brick (fired) is ₹ 5 ~7.

Thus, the development of GGBS-lime treated jarosite bricks is much cheaper as compared to conventional bricks available in market.

*(**Note-** The above cost figure is influenced by **hauling distance of materials**. For example, if we take GGBS hauling distance at about **500 km,** then the cost of brick comes to ~ ₹ **3.00)**

4.3 Construction Sequence and QA/QC Procedure

As per the requirement and mode of application, suitable jarosite-GGBS-lime proportion will be used satisfactory and economically in various application of civil engineering (Table 4.1). After fixation of mix proportion, jarosite, GGBS and lime will be placed on existing soil subgrade and then dry mixed thoroughly to achieve uniformity. Afterward, the water will be added as per OMC and wet mixing will be carried out using a plow and dozer. Rolling and compaction (using road roller/vibratory roller) will be done until the required density is achieved. After compacting, it should be allowed to gain strength for a minimum of 28 days before using it. Furthermore, the treated jarosite will be checked for Quality Assurance/ Quality Control procedures, in which test pits will be made and

samples collected by core cutter for testing in a laboratory for strength. This will ensure the quality of the embankment or subgrade etc. Figure 4.2 illustrates the flow chart for construction sequence and QA/QC procedure involved in design of embankment/subgrade etc. constructed with treated/stabilized jarosite.

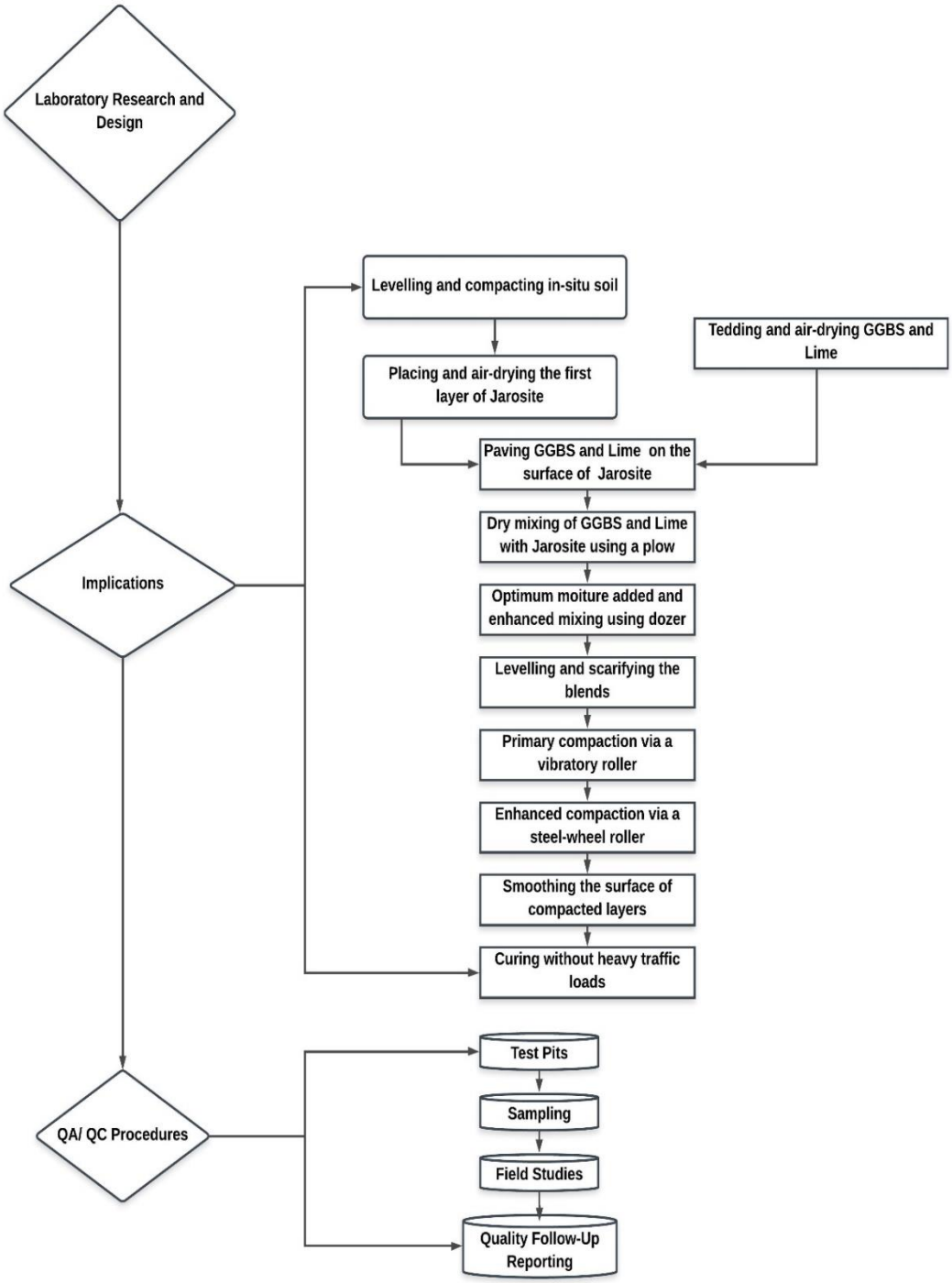

Figure 4.2 Flow chart of the construction procedure for GGBS-lime treated jarosite embankment/subgrade etc