INTRODUCTION

This chapter highlights the following aspects like Ferrochrome slag, an industrial solid waste, Problem Statements, formulation of solutions followed by Objective of the study, and organization of the of the report.

1.1 Waste utilization: the need of the hour

Large amount of unmanaged solid waste particularly from industries in the form of slag, ash, char and dust etc has resulted in an increased environmental concern. Recycling/reuse of such wastes as sustainable construction material appears to be a viable solution not only to pollution problem but also an economical option for design of green buildings. Building sectors consume a lot of construction material and most of these are derived from natural sources. With the increase in population and the consequent phenomenal growth of building sector, there is ever increasing demand for construction material. Excessive consumption of natural resources in building and construction sectors has led to serious problems of resource depletion and environmental degradation. Most the slag from the metallurgical industries possess good mechanical and engineering properties; therefore have the suitability in many construction and building applications. But these materials usually contain environmentally harmful substances which very often limit their useful application. If this waste material is found to be technically sound and economically feasible, they might contribute to solving some of the aggregate supply problems and to the conservation of natural resources. Therefore there is a need for elaborate technical and environmental assessment of the waste material to evaluate their suitability and environmental compatibility in utilisation scenario. The present research work takes up the case of a problematic industrial waste of ferrochrome slag to evaluate its technical and environmental aspects for its useful application.
1.2 Manufacturing of Ferrochrome alloy and generation of Slag

Ferrochrome is the most common alloying material for the production of different grades of stainless steel. Chromium and iron in the chromite ore can form a continuous series of solid solution under certain condition of heat treatment containing 45-80% of chromium. Ferrochrome is manufactured through direct smelting in Submerged Arc Furnace (SAF) at a temperature of above 1200°C. The furnace has the suitable system for tapping heavier metal and lighter slag and their handling. Manufacturing process is shown in Fig 1.1

![Ferrochrome Manufacturing Process](image)

Fig. 1.1 Ferrochrome Manufacturing Process

For the production of each MT of Ferrochrome about 2.5-2.6 MT of chromite ore, 0.5-0.6 MT of coke and 0.3 MT of fluxing agent are required. There is generation of 1 to 1.2 MT of solid waste slag per MT of Ferrochrome product. [49] The waste slag is reported to contain the major chemical constituents like SiO$_2$, Al$_2$O$_3$ and MgO etc. It also contains
appreciable amount of environmentally harmful chromium compounds [89]. When the molten slag is allowed to cool normally under air, the slag is available as large size lumpy material contaminated with small amount of Ferrochrome metal dispersed in the slag matrix. Therefore the lumped slag material is reduced in size to recover the metal through jigging. The waste slag after metal recovery is available in the desirable size range for reuse. Alternatively, when the molten slag is cooled with high pressure water jet resulting in crystalline granulated slag. Both the lumpy slag and granulated products can have useful applications. The waste slag material thus is available in different sizes under different cooling conditions and after material recovery Material Balance in Ferrochrome process is shown in Fig.1.2.

![Material Balance](image)

**Fig.1.2 Material Balance in Ferrochrome process.**

### 1.3 Chromium pollution problems in the Environment

Chromium is one of the most common toxic heavy metals found in the environment. Two ionic forms of chromium, Cr (III) and Cr (VI), are present in various forms in soil, water and in the biota. The dumping ferrochrome slag significantly increases chromium concentration in soil and the resulting groundwater contamination. Hexavalent chromium is found to be the most mobile chromium form in soil and water systems,
whereas Cr (III) is generally not transported over great distances because of its low solubility and tendency to be absorbed by solid particles in the appropriate pH range. Severe and often deadly pathological changes are associated with excessive intake of Cr (VI) compounds. Cr (VI) exerts toxic effects on biological systems. It has been reported that occupational exposure to hexavalent chromium compounds leads to a variety of clinical problems. Inhalation and retention of materials containing Cr (VI) can cause perforation of the nasal septum, asthma, bronchitis, and pneumonitis, inflammation of the larynx and liver and increased incidence of bronchogenic carcinoma. Skin contact of Cr (VI) compounds can induce skin allergies, dermatitis, dermal necrosis and dermal corrosion[57, 118, 119] As per Occupational Safety Health Administration OSHA [95], the major health effects associated with exposure to Cr (VI) include lung cancer, nasal septum ulcerations and perforations, skin ulcerations, and allergic and irritant contact dermatitis etc.

1.4 Identification of problem

The waste ferrochrome slag from ferrochrome industries is reported to contain about 8 to 12% environmentally harmful chromium compounds. The industry faces the disposal problem of slag for obvious reasons of residual chromium content in the slag, which may leach out from the slag matrix and may cause serious pollution problem in surface water and ground water. That is why before disposal, slag is subjected through TCLP (Toxicity Characteristic Leaching Procedure) test for Cr$^{6+}$ and total chromium content. The slag is considered to be Hazardous waste, in the event of failure in TCLP test for regulatory compliance with respect to Cr$^{6+}$ and total chromium content. That is why there exists stringent Indian discharge standard such as 2.0 mg/l for total chromium (total Cr) and 0.1 mg/l for Cr (VI) [35]. The waste slag is reported to have good mechanical and engineering properties and the therefore can be utilized in many construction applications [137]. But because of the presence of significant amount of residual chromium in the slag restricts its use or disposal. Therefore the disposal of this waste is a serious problem faced by the industry. Keeping the aforesaid industrial problem in mind, the proposed research work was undertaken to find the satisfactory solution of management/disposal problem of this waste slag. Considering the good engineering properties of the slag, its utilization potential is to be considered.
1.5 **Objective of the study**

Having identified the problem and, this present work was under-taken with the following objective.

- Evaluation of chromium leachability from the slag matrix
- Study of chromium immobilization mechanism
- Modelling of the chromium leaching behaviour from the slag matrix to assess the long term leaching behaviour.
- Technical assessment of ferrochrome slag as reusable material.
- Appraisal of Environmental Compatibility of ferrochrome slag in reuse/disposal scenario.

1.6 **Organization of the Report**

The Thesis report comprises of eight chapters dealing with the entire research work.

- **Chapter 1: Introduction** highlights the following aspects like Ferrochrome slag, an industrial solid waste, problem statements and the objective of the present research work.

- **Chapter 2: Review of Literature** highlights the findings the published work in the following broad areas of research work like Characterization study of waste slag particularly Ferrochrome slag, study of toxic heavy metal particularly chromium leaching from the waste slag, toxic heavy metal/chromium immobilization mechanism, utilization of waste slag and modelling the toxic heavy metal particularly chromium leaching behaviour from slag matrix.

- **Chapter 3: Characterization study of Ferrochrome slag** discusses and analyses the results of the following Characterization studies like physical properties, major chemical and trace element analysis study, mineralogical Characterization study and microscopic Characterization study of Ferrochrome slag.

- **Chapter 4: Study of Chromium Leaching from Ferrochrome slag** discusses and analyses the results of the chromium leaching from unbound and concrete bound Ferrochrome slag samples under various leaching test methods. The important
aspects include, selection of leach test methods, experimental methods and analysis of results of chromium leaching from unbound ferrochrome slag under various environmental conditions, experimental methods and analysis of results of chromium leaching from concrete bound slag samples.

**Chapter 5: Study of Chromium Immobilization mechanism in Ferrochrome slag**

analyses the review and experiment methods of the following Chromium Immobilization mechanism like review of inherent Chromium Immobilization mechanism in Ferrochrome slag and experimental methods and analysis of Chromium Immobilization mechanism in Cement matrix.

**Chapter 6: Study of Utilization of Ferrochrome slag as Concrete Aggregate Material**
evaluates technical and environmental aspects relating to Utilization slag as Concrete Aggregate Material. This chapter discusses the important aspects like experimental design and assessment of air cooled lumpy Ferrochrome slag as coarse aggregate in concrete, experimental design and assessment of water cooled granulated Ferrochrome slag as fine aggregate in concrete and Environmental compatibility of concrete with Ferrochrome slag as aggregate material.

**Chapter 7: Study of Modelling the Chromium leaching behaviour from slag matrix**

analyses the different Modelling results to interpret the different leaching mechanisms like modelling the long term chromium leaching from unbound slag matrix, Full Factorial Design modelling results to analyse the various factors affecting the leaching and Dynamic Leach Test modelling to analyse the process mechanisms involved in the leaching process.

**Chapter 8: Conclusions**
interprets various conclusions of the present research work and evaluates relevance of this work in the present context. At the same time the scope for further work is presented.