Fig. 1.1	The solid waste management hierarchy	3
Fig. 1.2	Country wise coal production around the globe	6
Fig. 1.3	Sampling location of FA and CT	8
Fig. 1.4	Methodology adopted in the research work	10
<b>Fig. 2.1</b>	Different application of fly ash based on the inherent parameters	19
Fig. 3.1	Dumping fly ash site near Suratgarh Super thermal power plant,	29
	Suratgarh, Sri Ganganagar, Rajasthan, India	
Fig. 3.2	Copper tailings dumping site near Khetri Copper Complex, Hindustan	30
	Copper Limited (HCL) district Jhunjhunu, Rajasthan, India	
Fig. 3.3	Basic schematic representation behind powder X-Ray diffraction	33
Fig. 3.4	XRD results of Fly ash	35
Fig. 3.5	XRD results of copper tailings	36
<b>Fig. 3.6</b>	Basic schematic representation behind X-Ray Fluorescence	37
	Spectroscopy	
<b>Fig. 3.7</b>	Process followed in SEM analysis	39
<b>Fig. 3.8</b>	Fly ash SEM results at different magnification levels	40
<b>Fig. 3.9</b>	Copper tailings SEM results at different magnification levels	41
Fig. 3.10	OPC SEM results at different magnification levels	42
<b>Fig 4.1</b>	The movement of waste material and liquid in the environment	46
<b>Fig. 4.2</b>	Collection of groundwater samples near Khetri Copper Lailing pond,	49
	Khetri	
<b>Fig. 4.3</b>	Batch leaching test performed in the laboratory	51
<b>Fig 4.4</b>	Overview of the column leaching experiment set up	52
Fig 4.5	Experimental setup in the laboratory	53
<b>Fig. 4.6</b>	Concentration of elements in FA-1 and FA-2 (all values are in mg kg-	54
	1) (x-axis plotted on a log scale to visualize the difference properly)	
Fig. 4.7	pH of batch leaching test under different L/S ratio	56
<b>Fig. 4.8</b>	Concentration of Al in leachate of TCLP batch leaching test for FA and	61
	CT individually and in combination of different mix proportions	

Fig. 4.9	Concentration of Al in leachate of ASTM batch leaching test for FA	61
	and CT individually and in combination of different mix proportions	
Fig. 4.10	Concentration of As in leachate of TCLP batch leaching test for FA	62
	and CT individually and in combination of different mix proportions	
Fig. 4.11	Concentration of As in leachate of ASTM batch leaching test for FA	62
	and CT individually and in combination of different mix proportions	
Fig. 4.12	Concentration of Ba in leachate of TCLP batch leaching test for FA	63
	and CT individually and in combination of different mix proportions	
Fig. 4.13	Concentration of BA in leachate of ASTM batch leaching test for FA	63
	and CT individually and in combination of different mix proportions	
Fig. 4.14	Concentration of Cd in leachate of TCLP batch leaching test for FA	64
	and CT individually and in combination of different mix proportions	
Fig. 4.15	Concentration of Cd in leachate of ASTM batch leaching test for FA	64
	and CT individually and in combination of different mix proportions	
Fig. 4.16	Concentration of Co in leachate of TCLP batch leaching test for FA	65
	and CT individually and in combination of different mix proportions	
Fig. 4.17	Concentration of Co in leachate of ASTM batch leaching test for FA	65
	and CT individually and in combination of different mix proportions	
Fig. 4.18	Concentration of Cr in leachate of TCLP batch leaching test for FA and	66
	CT individually and in combination of different mix proportions	
Fig. 4.19	Concentration of Cr in leachate of ASTM batch leaching test for FA	66
	and CT individually and in combination of different mix proportions	
Fig. 4.20	Concentration of Cu in leachate of TCLP batch leaching test for FA	67
	and CT individually and in combination of different mix proportions	
Fig. 4.21	Concentration of Cu in leachate of ASTM batch leaching test for FA	67
	and CT individually and in combination of different mix proportions	
Fig. 4.22	Concentration of Fe in leachate of TCLP batch leaching test for FA and	68
	CT individually and in combination of different mix proportions	
Fig. 4.23	Concentration of Fe in leachate of ASTM batch leaching test for FA	68
	and CT individually and in combination of different mix proportions	

Fig. 4.24	Concentration of Mg in leachate of TCLP batch leaching test for FA	68
	and CT individually and in combination of different mix proportions	
Fig. 4.25	Concentration of Mg in leachate of ASTM batch leaching test for FA	69
	and CT individually and in combination of different mix proportions	
Fig. 4.26	Concentration of Mn in leachate of TCLP batch leaching test for FA	70
	and CT individually and in combination of different mix proportions	
Fig. 4.27	Concentration of Mn in leachate of ASTM batch leaching test for FA	70
	and CT individually and in combination of different mix proportions	
Fig. 4.28	Concentration of Ni in leachate of TCLP batch leaching test for FA and	71
	CT individually and in combination of different mix proportions	
Fig. 4.29	Concentration of Ni in leachate of ASTM batch leaching test for FA	71
	and CT individually and in combination of different mix proportions	
Fig. 4.30	Concentration of Pb in leachate of TCLP batch leaching test for FA and	72
	CT individually and in combination of different mix proportions	
Fig. 4.31	Concentration of Pb in leachate of ASTM batch leaching test for FA	72
	and CT individually and in combination of different mix proportions	
Fig. 4.32	Concentration of Se in leachate of TCLP batch leaching test for FA and	73
	CT individually and in combination of different mix proportions	
Fig. 4.33	Concentration of Se in leachate of ASTM batch leaching test for FA	73
	and CT individually and in combination of different mix proportions	
Fig. 4.34	Concentration of Sr in leachate of TCLP batch leaching test for FA and	74
	CT individually and in combination of different mix proportions	
Fig. 4.35	Concentration of Sr in leachate of ASTM batch leaching test for FA	74
	and CT individually and in combination of different mix proportions	
Fig. 4.36	Concentration of Ti in leachate of TCLP batch leaching test for FA and	75
	CT individually and in combination of different mix proportions	
Fig. 4.37	Concentration of Ti in leachate of ASTM batch leaching test for FA	75
	and CT individually and in combination of different mix proportions	
Fig. 4.38	Concentration of V in leachate of TCLP batch leaching test for FA and	76
	CT individually and in combination of different mix proportions	

Fig. 4.39	Concentration of V in leachate of ASTM batch leaching test for FA and	76
	CT individually and in combination of different mix proportions	
Fig. 4.40	Concentration of Zn in leachate of TCLP batch leaching test for FA	77
	and CT individually and in combination of different mix proportions	
Fig. 4.41	Concentration of Zn in leachate of ASTM batch leaching test for FA	77
	and CT individually and in combination of different mix proportions	
Fig. 4.42	Al concentration in column leaching results for different types of	83
	leachant	
Fig. 4.43	As concentration in column leaching results for different types of	84
	leachant	
Fig. 4.44	Ba concentration in column leaching results for different types of	85
	leachant	
Fig. 4.45	Cd concentration in column leaching results for different types of	86
	leachant	
Fig. 4.46	Co concentration in column leaching results for different types of	87
	leachant	
Fig. 4.47	Cr concentration in column leaching results for different types of	88
	leachant	
Fig. 4.48	Cu concentration in column leaching results for different types of	89
	leachant	
Fig. 4.49	Fe concentration in column leaching results for different types of	90
	leachant	
Fig. 4.50	Mg concentration in column leaching results for different types of	91
	leachant	
Fig. 4.51	Mn concentration in column leaching results for different types of	92
	leachant	
Fig. 4.52	Ni concentration in column leaching results for different types of	93
	leachant	
Fig. 4.53	Pb concentration in column leaching results for different types of	94
	leachant	

Fig. 4.54	Se concentration in column leaching results for different types of	95
	leachant	
Fig. 4.55	Sr concentration in column leaching results for different types of	96
	leachant	
Fig. 4.56	Ti concentration in column leaching results for different types of	97
	leachant	
Fig. 4.57	V concentration in column leaching results for different types of	98
	leachant	
Fig. 4.58	Zn concentration in column leaching results for different types of	99
	leachant	
Fig. 5.1	Production of cement in different countries	106
Fig. 5.2	Different steps of LCA and applications	109
Fig. 5.3	General procedure followed for cradle to grave approach in LCA to	111
	produce mixed design concrete	
Fig. 5.4	Framework of LCA analysis used in the study	115
Fig. 5.5	Midpoint life cycle assessment of climate change for concrete at w/c	118
	ratio 0.45 with different proportion of FA, CT, and Cement	
<b>Fig. 5.6</b>	Midpoint life cycle assessment of climate change for concrete at w/c	118
	ratio 0.5 with different proportion of FA, CT, and Cement	
Fig. 5.7	Midpoint life cycle assessment of human toxicity for concrete at w/c	119
	ratio 0.45 with different proportion of FA, CT, and Cemen	
Fig. 5.8	Midpoint life cycle assessment of human toxicity for concrete at w/c	119
	ratio 0.5 with different proportion of FA, CT, and Cement	
Fig. 5.9	Midpoint life cycle assessment of ozone depletion for concrete at w/c	120
	ratio 0.45 with different proportion of FA, CT, and Cement	
Fig. 5.10	Midpoint life cycle assessment of ozone depletion for concrete at w/c	120
	ratio 0.5 with different proportion of FA, CT, and Cement	
Fig. 5.11	Midpoint life cycle assessment of agriculture land occupation for	121
	concrete at w/c ratio 0.45 with different proportion of FA, CT, and	
	Cement	

Fig. 5.12	Midpoint life cycle assessment of agriculture land occupation for	121
	concrete at w/c ratio 0.5 with different proportion of FA, CT, and	
	Cement	
Fig. 5.13	Midpoint life cycle assessment of water depletion for concrete at w/c	123
	ratio 0.45 with different proportion of FA, CT, and Cement	
Fig. 5.14	Midpoint life cycle assessment of water depletion for concrete at w/c	123
	ratio 0.5 with different proportion of FA, CT, and Cement	
Fig. 5.15	Midpoint life cycle assessment of fossil depletion for concrete at w/c	124
	ratio 0.45 with different proportion of FA, CT, and Cement	
Fig. 5.16	Midpoint life cycle assessment of fossil depletion for concrete at w/c	124
	ratio 0.5 with different proportion of FA, CT, and Cement	
Fig. 5.17	Midpoint life cycle assessment of particulate matter for concrete at w/c	123
	ratio 0.45 with different proportion of FA, CT, and Cement	
Fig. 5.18	Midpoint life cycle assessment of particulate matter for concrete at w/c	126
	ratio 0.5 with different proportion of FA, CT, and Cement	
Fig. 5.19	Midpoint life cycle assessment of metal depletion potential for concrete	126
	at w/c ratio .45 with different proportion of FA, CT, and Cement	
Fig. 5.20	Midpoint life cycle assessment of metal depletion potential for concrete	127
	at w/c ratio 0.5 with different proportion of FA, CT, and Cement	
Fig. 5.21	Endpoint environmental impacts for damage to ecosystem quality at	129
	w/c ratio 0.45 for different mix of concrete	
Fig. 5.22	Endpoint environmental impacts for damage to ecosystem quality at	129
	w/c ratio 0.5 for different mix of concrete	
Fig. 5.23	Endpoint environmental impacts for damage to human health at w/c	130
	ratio 0.45 for different mix of concrete	
Fig. 5.24	Endpoint environmental impacts for damage to human health at w/c	130
	ratio 0.5 for different mix of concrete	
Fig. 5.25	Endpoint environmental impacts for damage to resources availability at	131
	w/c ratio 0.45 for different mix of concrete	
Fig. 5.26	Endpoint environmental impacts for damage to resources availability at	131
	w/c ratio 0.5 for different mix of concrete	

Fig. 5.27	Cost reduction in percentage in different category mix with respect to	133
	control mix	
Fig. 6.1	Processed follows for the compressive strength assessment of modified	139
	concrete	
Fig. 6.2	Formation of supplementary cementitious material after the partial	141
	replacement of cement with pozzolanic material	
Fig. 6.3	FA, CT, Cement, sand, aggregate, admixture, and water used in the	142
	experiment	
Fig. 6.4	Preparing concrete and casting the cubes	143
Fig. 6.5	Testing the compressive strength of casted cube	144
Fig 6.6	Stress-strain behavior of mix M1 for w/c ratio 0.45	147
<b>Fig. 6.7</b>	Stress-strain behavior of mix M2 for w/c ratio 0.45	147
Fig. 6.8	Stress-strain behavior of mix M3 for w/c ratio 0.45	148
Fig. 6.9	Stress-strain behavior of mix M4 for w/c ratio 0.45	148
Fig. 6.10	Stress-strain behavior of mix M5 for w/c ratio 0.45	149
Fig. 6.11	Stress-strain behavior of mix M6 for w/c ratio 0.45	149
Fig 6.12	Stress-strain behavior of mix M1 for w/c ratio 0.5	150
Fig. 6.13	Stress-strain behavior of mix M2 for w/c ratio 0.5	150
Fig. 6.14	Stress-strain behavior of mix M3 for w/c ratio 0.5	151
Fig. 6.15	Stress-strain behavior of mix M4 for w/c ratio 0.5	151
Fig. 6.16	Stress-strain behavior of mix M5 for w/c ratio 0.5	152
Fig. 6.17	Stress-strain behavior of mix M6 for w/c ratio 0.5	152
Fig. 6.18	Stress-strain behavior of control mix for w/c ratio 0.45	153
Fig. 6.19	Stress-strain behavior of control mix for w/c ratio 0.5	153
Fig. 6.20	7- days compressive strength test results of modified concrete mix	152
	proportions	
Fig. 6.21	28- days compressive strength test results of modified concrete mix	153
	proportions	
Fig. 6.22	56- day compressive strength test results of modified concrete mix	153
	proportions	

Fig 6.23	Variation in 56-days compressive strength with control mix for w/c	154
	ratio 0.45	
Fig 6.24	Variation in 56-days compressive strength with control mix for w/c	155
	ratio 0.5	

Table 1.1	Classification of solid waste	2
Table 2.1	Research work done related to utilization of fly ash in different areas	19
Table 2.2	Research work done related to the utilization of copper tailings in	23
	different fields	
Table 3.1	Location of sites for the sampling of groundwater near copper tailing	31
	pond	
Table 3.2	Location of sites for the sampling sites of groundwater near Suratgarh	32
	super thermal power plant	
Table 3.3	XRF analysis results of fly ash, copper tailings, and OPC	38
Table 3.4	Physical parameters in copper tailings, fly ash and OPC	43
Table 4.1	Observed concentration of selected elements in representative leachate	57
	samples viz. FA-1 and FA-2 through TCLP and ASTM	
Table 4.2	Regression analysis of combined (FA and CT) ASTM batch leaching	81
	results	
Table 4.3	Regression analysis of combined (FA and CT) TCLP batch leaching	82
	results	
Table 4.4	Heavy Metal Concentration in groundwater samples near Khetri	101
	copper tailings pond (mg/L)	
<b>Table. 4.5</b>	Heavy metal Concentration in groundwater samples collected from	102
	the nearby FA dumping site	
Table 5.1	Mix design details of different proportion used for casting concrete	114
	cubes of target compressive strength of 30 MPa	
Table 5.2	Cost analysis of one m <sub>3</sub> of concrete for mix combination M1, M2, M3,	134
	M4, M5 and M6 for water-cement ratio 0.45	
Table 5.3	Cost analysis of one m <sub>3</sub> of concrete for mix combination M1, M2, M3,	135
	M4, M5 and M6 for water-cement ratio 0.5	
Table 6.1	Chemical composition and physical properties of cement, copper	140
	tailings and fly ash	

Table 6.2	Mix design details of different proportion used for casting concrete	145
	cubes	
Table 6.3	Secant modulus for all mix proportions after 7-days and 28-days and	154
	56-days	

## **Abbreviations**

AMD Acid Mine Drainage

ASTM American Society for Testing and Materials

CFC Chlorofluorocarbon
CT Copper Tailings

FA Fly Ash

FEG-SEM Field Emission Gun Scanning Electron Microscopy

FFP Fossil Fuel Potential

GWP Global Warming Potential
HCL Hindustan Copper Limited

ICP-AES Inductively Coupled Plasma Atomic Emission Spectroscopy

ICP-MS Inductively Coupled Plasma Mass Spectrometry

LCA Life Cycle Assessment
LCI Life Cycle Inventory

LCIA Life Cycle Impact Analysis

LEAF Leaching Environmental Assessment Framework

NMDC National Mineral Development Corporation

ODP Ozone Depletion Potential

OECD Organization for Economic Co-Operation and Development

OPC Ordinary Portland Cement

SETAC Society for Environmental Toxicology and Chemistry

TCLP Toxicity Characteristic Leaching Procedure

US EPA United States Environmental Protection Agency

USGS United States Geological Survey

UTM Universal Testing Machine
WHO World Health Organization
XRD X-Ray Powder Diffraction

XRF X-Ray Fluorescence