

List of Tables

2.1 Decomposition of cement paste at various temperatures ranges	8
2.2 Deemed-to-satisfy Specifications in BSLJ.....	13
2.3 Coefficient thermal expansion of some types of aggregate.....	49
3.1: Chemical analysis of CEM I.....	70
3.2: Physical properties of fine and coarse aggregate.....	70
3.3: ASTM C 33/84 requirements and percentage passing by weight of Fine aggregate.....	71
3.4: ASTM C 33/84 requirements and percentage passing by weight of coarse aggregate.....	71
3.5: Maximum allowable chemical impurities in water used for mixing and curing of concrete.....	73
3.6: Chemical compositions and physical properties of silicafume and bentonite.....	74
3.7: Physical properties of limestone powder (LP).....	74
3.8: EDAX analysis of ceramic powder.....	75
3.9: EDAX analysis of melamine powder.....	76
3.10: EDAX analysis of brick clay powder.....	77
3.11: Physical properties of polypropylene fibers.....	78
3.11: Abridged terms of the concrete mixtures.....	83
3.12: Details of concrete mixes.....	84
4.1: Compressive strength results of conventional (control) concrete after exposure to 20, 200, 400 and 600°C for 2 hrs.....	94
4.2: Tensile strength results of conventional (control) concrete after exposure to different elevated temperatures for 2 hrs.....	96
4.3: Flexural strength results of conventional (control) concrete after exposure to todifferent elevated temperaturesfor 2 hrs.....	98
4.4: Relative compressive strength under air and water cooling regime.....	101
4.5: Temperature of reinforcement, unexposed and exposed surface of conventional concrete slabs exposed to 600°C for 2 hrs and air cooled for 2 hrs.....	107

4.6: Temperature of reinforcement, unexposed and exposed surface of conventional concrete slabs exposed to 800°C for 2 hrs and air cooled for 2 hrs.....	108
4.7: Temperature of reinforcement, unexposed and exposed surface of conventional concrete slabs exposed to 1200°C for 2 hrs and air cooled for 2 hrs.....	109
4.8: Temperature of the Rft inside conventional concrete slabs with 25, 50 and 75 mm cover thickness during exposure to 800°C for 2 hrs and air cooled for 2 hrs.....	112
4.9: Compressive strength of concrete specimens at room temperature and after exposed to 200, 400 and 600°C for 2 hrs.....	115
4.10: Weight Loss (%) of all concrete mixtures at 20, 200, 400 and 600° C.....	125
4.11 Temperature of Rft, unexposed and exposed surface of reinforced concrete slabs with 10% bentonite as cement replacement.....	173
4.12: Relative temperatures of steel and unexposed surface of slabs after exposed to 600°C for 2 hrs.....	176
4.13: Relative temperatures of steel and unexposed surface of slabs after exposed to 800°C for 2 hrs.....	177
4.14: The temperature of exposed and unexposed surface of the concrete slabs after 2hrs of air cooling regime.....	179
4.15: Relative compressive strength of control mortar, 10 and 20% ceramic powder as cement replacement.....	183
4.16: TGA weight loss for unheated control mix.....	190
4.17: TGA weight loss for unheated and preheated limestone portland cement mix at 600°C.....	191
92	
4.18: Weight loss for unheated and preheated 20% bentonite mortar according to TGA/DTG.....	194
4.19: Weight loss for unheated and preheated 10% ceramic mortar according to TGA/DTG.....	195
4.20: Weight loss for unheated and preheated 10% melamine mortar according to TGA/DTG.....	197
4.21: Temperature of unexposed and exposed surface of reinforced concrete roof of the experimented room.....	207

5.1: TGA weight loss (%) of unheated and preheated conventional concrete at 200, 400 and 600°C for 0.5, 1 and 2 hrs.....	218
6.1: Ranges of used variables in database.....	226
6.2: The statistical values of proposed models.....	230
6.3: Serial number that used in modeling.....	231
6.4: Input and Output variables.....	231
6.5: Actual, predicted and error values of 28 days cube compressive strength of concrete at different elevated temperature 20, 200, 400 and 600°C using ANN technique....	232
6.6: The statistical values of proposed models.....	236

List of Figures

2.1- Thermal strains for different concretes, aggregates and hydrated cement paste.....	10
2.2- Functional requirements for fire resistance.....	11
2.3- Three Routes to Conform with Fire Resistance Requirements in BSLJ.....	12
2.4 - Typical changes in load and strength of steel column during fire.....	13
2.5- Calculation Procedure of Critical Time to Failure by Simplified Verification Method.....	14
2.6- Compressive strength of concrete at high temperatures and design strength.....	16
2.7- Temperature profiles against distance from fire-exposed surface as a function of Time.....	16
2.8- Load level in fire design.....	18
2.9- Design methods for standard fire.....	19
2.10 - High strength concrete, strength reduction classes.....	20
2.11- Reference temperature for shear reinforcement.....	20
2.12- Compressive strength of siliceous aggregate concrete: ACI-216.....	23
2.13- Compressive strength of carbonate aggregate concrete: ACI-216.....	24
2.14- Compressive strength of semi-lightweight concrete: ACI 216.....	24
2.15- Performance-based structural fire engineering (PBSFE) design process.....	28
2.16- Schematic of temperature and loading histories for the three test methods.....	31
2.17- Temperature sensitivity of compressive strength when tested hot (unsealed-unstressed).....	33

2.18- Temperature sensitivity of compressive strength when tested cold (unsealed-unstressed).....	33
2.19- Effect of aggregate on concrete strength materials exposed to high temperatures.....	34
2.20- Unsealed PCPV concrete specimens tested hot (H) and cold (C).....	35
2.21- Unstressed High Temperature Data of NSC vs HSC.....	35
2.22- Stressed High Temperature Data of NSC vs HSC.....	36
2.23- High Temperature Models for NSC Concrete.....	37
2.24- High Temperature Models for HSC Concrete.....	38
2.25- Hot isothermal test results obtained by Abrams.....	39
2.26- Residual compressive strength obtained by Morita et al.....	40
2.27- Compressive strength vs. Temperature under hot isothermal conditions.....	41
2.28- Unstressed residual tensile strength obtained by Noumowe et al.....	42
2.29- The effects of loading and temperature during heating in uniaxial compression of unsealed concrete specimens.....	43
2.30- Effect of temperature upon the residual (after cooling) compressive strength and elastic modulus of unsealed C70 HITECO Concrete -20 percent load: expressed as a percentage of strength prior to heating.....	44
2.31- Modulus of Elasticity under hot conditions by Castillo and Durani.....	45
2.32- Hot isothermal test results obtained by (a), (b) Morita et al.,1992 and (c) Noumowe et al., 1996, and (d) Furumura et al., 1995.....	45
2.33- The effect of cooling methods on modulus of elasticity of concrete.....	46
2.34- Hot isothermal test results obtained by Castillo and Durani.....	47
2.35- Hot isothermal test results obtained by Furumura et al.....	47
2.36- Stress-strain curves of concrete specimens by (1) normal cooling, (2) slow cooling, and (3) fast (water) cooling after heating to 200, 400, 600, and 800 °C.....	48
2.37- Thermal strain of concrete vs. temperature.....	50
2.38- Coefficient of thermal expansion of concrete vs. temperature.....	50
2.39- Shrinkage of concrete under different temperatures (Schneider 2002).....	51
2.40- Illustration of mechanism of spalling of concrete as a result of fire loading according to Refs. (Consolazio 1997 and Schneider, 2002).....	54
2.41- Temperatures within slabs during fire tests sanded light weight concrete.....	55

2.42-Temperature distribution in normal weight rectangular unit at 1,2,3hrs of fire exposure.....	56
2.43 - Residual compressive strength.....	57
2.44 - Residual elastic modulus.....	57
2.45 - Cumulative distribution of pore size.....	58
2.46 - Differential distribution of pore size.....	58
2.47-(a)-After heating to 150°C, the fibers are still there (melting temp. ≈150-170°C).....	59
2.47 (b) - After heating to 300°C, only the mark of the fibers is left.....	59
2.48-Evolution of the micro-cracks in the specimens first slowly heated to high temperature and then cooled to room temperature.....	59
2.49- Raw materials of limestone powder.....	60
2.50-Polypropylene fibers (PPF).....	61
2.51-Microcrackingnetwork.....	63
3.1- Grading of sand according to ASTM specifications.....	72
3.2-Grading of pink lime stone according to ASTM specifications.....	72
3.3-XRD analysis of used limestone powder (LP).....	74
3.4-EDAX analysis of used ceramic powder (C.P).....	75
3.5-EDAX analysis of used melamine powder (M.P).....	76
3.5-EDAX analysis of used brick clay (B.C).....	77
3.7- Beams before flexural test.....	79
3.8- Small scale slabs.....	80
3.9-Reinforced concrete slab with embedded thermocouples to investigate the effect of the cover thickness on the reinforcement’s temperature.....	81
3.10- a) Slabs during pouring the plaster b) Slab after plastering.....	81
3.11- Electric oven.....	85
3.12- Gas oven.....	85
3.13- Compression testing machine.....	86
3.14-Concrete cylinder under compression machine to evaluate splitting tensile strength.....	87
3.15- Flexural testing machine.....	87
3.16- Fluke 568 IR thermometer laser apparatus.....	88

3.17 – Pull out specimen under testing machine.....	89
3.18 - The thermogravimetric analyzer (Thass-TGA I 1000).....	90
3.19 - SEM instrument, JEOL-JSM-5300.....	91
3.20 Coating samples with nano- layer of gold before test.....	91
3.21 -Two amplifies lens.....	92
4.1 - Relative compressive strength of the mixture at room temperature and residual compressive strength after exposure to 200, 400 and 600°C for 2 hrs.....	95
4.2 -Relative tensile strength of the control mixture at room temperature and after exposure to 200, 400 and 600°C for 2 hrs.....	97
4.3 -Relative flexural strength of the control mixture at room temperature and after exposure to 200, 400 and 600°C for 2 hrs.....	98
4.4 -Relative weight loss of control concrete specimens subjected to elevated temperature up to 600°C.....	99
4.5 -Maps of cracking of control concrete specimens at 200, 400 and 600°C.....	100
4.6 - Relative compressive strength of conventional concrete after air and water cooling regime.....	102
4.7 - (TGA/DTG) curves of control mix a) TGA b) DTG.....	104
4.8 -SEM images of conventional concrete specimens after exposed to elevated temperature at 20, 200, 400 and 600°C.....	105
4.9 -Time – temperature curves of reinforcement inside reinforced conventional concrete slabs exposure to 600, 800 and 1200°C for 2 hrs and cooled by air for 2 hrs.....	110
4.10 -Time - temperature curves of unexposed surface of reinforced conventional concrete slabs exposure to 600, 800 and 1200°C for 2 hrs and cooled by air for 2 hrs.....	110
4.11 -Time-temperature curves of exposed surface of reinforced conventional concrete slabs exposure to 600, 800 and 1200°C for 2 hrs. and cooled by air for 2 hrs.....	111
4.12 -Time-temperature curves of reinforcement inside conventional concrete slabs with 25, 50 and 75 mm cover thickness during exposed to 800°C and cooled by air for 2 hrs.....	113

4.13- Relative pull out strength between the Rft and the concrete cylinder at room temperature and after exposed to different elevated temperature at 200, 400 and 600°C.....	114
4.14- Residual compressive strength of control and 10% silicafume concrete at room temperature and after exposed to elevated temperature at 200, 400 and 600°C.....	116
4.15- Residual compressive strength of control and polypropylene fiber concrete at room temperature and after exposed to elevated temperature at 200, 400 and 600°C.....	117
4.16- Residual compressive strength of control and (silicafume + polypropylene fiber) concrete at room temperature and after exposed to elevated temperature at 200, 400 and 600°C.....	118
4.17- Residual compressive strength of control and steel fiber concrete at room temperature and after exposed to elevated temperature at 200, 400 and 600°C.....	119
4.18- Residual compressive strength of control and limestone powder concrete at room temperature and after exposed to elevated temperature at 200, 400 and 600°C.....	120
4.19- Residual compressive strength of control and bentonite concrete at room temperature and after exposed to elevated temperature at 200, 400 and 600°C.....	121
4.20- Flexural strength of all concrete mixtures beams at 20, 200, 400 and 600°C.....	123
4.21 - Relative unit weight of all mixtures at 20°C.....	125
4.22 - % Weight loss of the mixtures at a) 200°C b) 400°C c) 600°C.....	127
4.23- SEM images of concrete with 10% silicafume as cement replacement at a) 20°C b) 200 c) 400 and d) 600°C.....	128
4.24- SEM images of concrete with 0.90 kg/m ³ polypropylene fibers at a) 20°C b) 200 c) 400 and d) 600°C.....	130
4.25 - Raw material of limestone powder under SEM.....	131
4.26- SEM images of 1-M-(L.F15R) 2-M-(L.F15A) at a) 20 b) 200 c) 400 and d) 600°C.....	133

4.27- SEM micrographs of raw bentonite at different magnifications: a) 2000× and b) 5000×.....	134
4.28- SEM images of concrete with 10% bentonite as cement replacement at a) 20°C b) 200 c) bentonite plates d) 400 e) 600°C.....	135
4.29- (TGA/DTG) curves of concrete with 10% silicafume as cement replacement by mass a) TGA b)DTG.....	137
4.30- (TGA/DTG) curves of concrete with 10% limestone powder as cement replacement by mass a) TGA b)DTG.....	139
4.31- (TGA/DTG) curves of concrete with 1°% limestone powder as cement replacement by mass a) TGA b) DTG.....	140
4.32 - (TGA/DTG) curves of concrete with 10% limestone powder as cement additive by mass a) TGA b) DTG.....	141
4.33 - (TGA/DTG) curves of concrete with 15% limestone powder as cement additive by mass a) TGA b) DTG.....	142
4.34 - (TGA/DTG) curves of concrete with 10% bentonite as cement replacement by mass a) TGA b) DTG.....	144
4.35- Maps of the cracks of concrete specimens with 10% silicafume as cement replacement.....	145
4.36- Maps of the cracks of concrete specimens containing 0.9 kg/m ³ polypropylene fibers.....	145
4.37 - Maps of the cracks of concrete specimens containing 10% silicafume as cement replacement with 0.9 kg/m ³ polypropylene fibers.....	146
4.38 - Maps of the cracks of concrete specimens containing 20 kg/m ³ steel fibers.....	146
4.39 - Maps of the cracks of concrete specimens containing LP as a partial cement replacement 1) M-(LP 10R) 2) M-(LP 15R).....	147
4.40 - Maps of the cracks of concrete specimens containing LP as an additive to cement content 1) M-(LP-10A) 2) M-(LP-15A).....	148
4.41 - Maps of the cracks of concrete specimens containing 10% bentonite as cement replacement at 600°C.....	149
4.42 - Temperature of Rft, unexposed and exposed surface of silicafume concrete slabs exposed to a) 600°C b)800°C.....	151

4.43 -Temperature of Rft, unexposed and exposed surface of 0.90kg/m ³ polypropylene fiber concrete slabs exposed to a) 600°C b) 800°C c)1200°C.....	154
4.44 -Temperature of Rft, unexposed and exposed surface of concrete slabs, with 10% silicafume as cement replacement and 0.90kg/m ³ polypropylene fiber, exposed to a) 600°C b) 800°C c)1200°C.....	157
4.45-Temperature of Rft, unexposed and exposed surface of 20 kg/m ³ steel fiber concrete slabs exposed to a) 600°C b) 800°C c)1200°C.....	160
4.46 -Temperature of Rft, unexposed and exposed surface of concrete slabs,with 10% L.P as cement replacement,exposed to a) 600°C b) 800°C c)1200°C.....	163
4.47 -Temperature of Rft, unexposed and exposed surface of concrete slabs,with 15% L.P as cement replacement,exposed to a) 600°C b) 800°C c)1200°C.....	166
4.48 -Temperature of Rft, unexposed and exposed surface of concrete slabs,with 10% L.P as cement additive,exposed to a) 600°C b) 800°C.....	168
4.49 -Temperature of Rft, unexposed and exposed surface of concrete slabs,with 15% L.P as cement additive,exposed to a) 600°C b) 800°C c)1200°C.....	171
4.50-Temperature of Rft, unexposed and exposed surface of concrete slabs,with 10% bentonite as cement replacement,exposed to a) 600°C b) 800°C c)1200°C.....	175
4.51 -Relative steel temperatures inside slabs exposure to 600°C for 2 hrs.....	176
4.52 -Relative unexposed surface temperatures of slabs exposure to 600°C for 2 hrs...	177
4.53 -Relative steel temperatures inside slabs exposed to 800°C for 2 hrs.....	178
4.54 -Relative unexposed surface temperatures of slabs exposed to 800°C for 2 hrs....	178
4.55-Relative compressive strength of conventional mortar at room temperature and after exposed to 200, 400 and 600°C.....	181
4.56-Relative compressive strength of limestone portland cement mortar at room temperature and after exposed to 200, 400 and 600°C.....	182
4.57 -Relative compressive strength of mortar containing 10 and 20% ceramic powder as a partial cement replacement.....	183
4.58 -Relative compressive strength of mortar containing 10 and 20% melamine powder as a partial cement replacement.....	184
4.59 -Relative compressive strength of mortar containing 10 and 20% brick clay powder as a partial cement replacement.....	186

4.60 -Relative compressive strength of mortar containing 10 and 20% bentonite as a partial cement replacement.....	187
4.61 -Mortar specimens with 10 and 20% bentonite as a cement replacement at 600°C.....	187
4.62 -Relative compressive strength of the conventional concrete cubes after the removal of the modified mortars cover after exposed to 600°C for 2 hrs.....	189
4.63 -Relative compressive strength of the modified mortars after exposed to 600°C for 2 hrs.....	189
4.64 -Temperature of the reinforcement inside the covered small scale concrete slabs by modified mortars after exposed to 1200°C for 2 hrs.....	190
4.65 -(TGA/DTG) curves of CEM I cement mortar (control mortar) a) TGA b) DTG.....	191
4.66 -(TGA/DTG) curves of limestone portland cement mortar a) TGA b) DTG.....	193
4.67 -(TGA/DTG) curves of 20% bentonite mortar a) TGA b) DTG.....	195
4.68 - (TGA/DTG) curves of 10% ceramic powder mortar a) TGA b) DTG.....	196
4.69 -(TGA/DTG) curves of 10% melamine powder mortar a) TGA b) DTG.....	198
4.70 -Weight loss of the all cube mixtures at a) 200 b) 400 c) 600°C.....	200
4.71 -SEM images of limestone cement mortar at a) 20°C b) 600°C.....	201
4.72 -SEM images of mortar with 10% bentonite as cement replacement at a) 20°C b) 600°C.....	202
4.73 -SEM of ceramic powder raw material.....	203
4.74 -SEM images of mortar with 10% ceramic powder as cement replacement at a) 20°C b) 600°C.....	204
4.75 -SEM of melamine powder raw material.....	205
4.76 -SEM image of the 10% melamine powder as cement replacement at a) 600°C.....	205
4.77 - SEM of brick clay powder raw material.....	206
4.78 - SEM images of brick clay concrete mix at a) 20°C b) 600°C.....	206
4.79 -Time-temperature relationship of exposed and unexposed surface of the roof of the experimented room.....	208
4.80 - Time-settlement relationship of the experimented roof slab.....	208
4.81 - Cracking of the concrete slab of the room during the fire.....	210

4.82 – Water evaporation during the fire.....	210
4.83 – Setup of the core.....	211
4.84 –a) Cracking in the unexposed surface of the roof slab b) Cracking in the supported beams c) The separation between roof slab and red brick clay walls.....	212
5.1 - (TGA/DTG) curves of unheated and preheated conventional concrete at 200° C for 0.5, 1 and 2 hrs. a) TGA b) DTG.....	215
5.2 - (TGA/DTG) curves of unheated and preheated conventional concrete at 400° C for 0.5, 1 and 2 hrs. a) TGA b) DTG.....	216
5.3 - (TGA/DTG) curves of unheated and preheated conventional concrete at 600° C for 0.5, 1 and 2 hrs. a) TGA b) DTG.....	217
5.4 - TGA weight loss (%) of unheated and preheated conventional concrete at 200, 400 and 600°C for different duration of exposure 0.5, 1 and 2 hrs.....	218
6.1 -A typical ANN topology with (n) input nodes, m and y hidden nodes, and t output nodes.....	222
6.2 - Topology of the prediction model.....	224
6.3 - Schematic of the input layer, hidden layer and output layer of the model as presented in ANN.....	225
6.4 - Logistic Curve.....	225
6.5 -Model-1: predicted vs. experimental steel temperature inside small scale concrete slab with 1 inch concrete cover thickness exposed to 800°C for 2 hrs.....	227
6.6 -Model-2: predicted vs. experimental steel temperature inside small scale concrete slab with 2 inch concrete cover thickness exposed to 800°C for 2 hrs.....	228
6.7 -Model-3: predicted vs. experimental steel temperature inside small scale concrete slab with 3 inch concrete cover thickness exposed to 800°C for 2 hrs.....	228
6.8 -Model-4: Over all predicted vs. experimental steel temperature inside small scale concrete slab with 1, 2, 3 inch concrete cover thickness exposed to 800°C for 2 hrs.....	229
6.9 -predicted vs. experimental cube compressive strength of the M-Control after exposed to 20, 200, 400 and 600°C for 2 hrs.....	232
6.10 -predicted vs. experimental cube compressive strength of the M-Silica after exposed to 20, 200, 400 and 600°C for 2 hrs.....	233

6.11 -predicted vs. experimental cube compressive strength of the M-(L.P.10R) after exposed to 20, 200, 400 and 600°C for 2 hrs.....	233
6.12 -predicted vs. experimental cube compressive strength of the M-(L.P.15R) after exposed to 20, 200, 400 and 600°C for 2 hrs.....	234
6.13 -predicted vs. experimental cube compressive strength of the M-(L.P.10A) after exposed to 20, 200, 400 and 600°C for 2 hrs.....	234
6.14 -predicted vs. experimental cube compressive strength of the M-(L.P.15A) after exposed to 20, 200, 400 and 600°C for 2 hrs.....	235
6.15 -predicted vs. experimental cube compressive strength of the M-(Ben.10R) after exposed to 20, 200, 400 and 600°C for 2 hrs.....	235
6.16 -The chosen model architecture.....	237
6.17 -Schematic of the input layer, hidden layer and output layer of the overall model as presented in ANN.....	238
6.18 -Overall predicted vs. experimental cube compressive strength of the all studied mixtures after exposed to 20, 200, 400 and 600°C for 2 hrs.....	238