

Contents

Abstract	iii
Contents	ix
List of symbols	xiii
List of figures	xiii
List of tables	xx
1 Introduction	1
1.1 Statement of problems	1
1.2 Research aims	2
1.2.1 Specific objectives	3
1.3 Thesis arrangement	4
2 State of the Art	5
2.1 Introduction	5
2.2 Fiber Reinforced Concrete (FRC)	5
2.2.1 Material properties	6
2.2.2 Use of steel fibers as shear reinforcement	9

2.3	Main ideas on shear behavior in cracked concrete	10
2.3.1	Failure modes	12
2.4	Shear transfer mechanisms across crack interfaces	14
2.4.1	Aggregate interlock	15
2.4.2	Dowel action	16
2.4.3	Influencing factors	17
2.5	Experimental tests on direct shear	18
2.5.1	Definition	19
2.5.2	Theories on direct shear	19
2.5.3	Test methodologies	22
2.5.4	Experimental results and mathematical models	28
2.5.5	Panels test	42
2.6	Conclusions	45
3	Design and development of test procedure	47
3.1	Introduction	47
3.2	Concepts and definitions of the test	48
3.2.1	Push-off concept	48
3.2.2	Specimen	50
3.2.3	Restraint frame	54
3.2.4	Ball bearing	57
3.2.5	Allowed initial crack width (w_o)	58
3.3	Initial design and first approach	59
3.3.1	First approach to the restraint frame	59
3.3.2	Procedure to set w_o	60
3.3.3	Precracking baseplate	61
3.3.4	Preliminary tests	61
3.3.5	Testing procedure and instrumentation	62
3.3.6	Results of the precracking phase	66
3.3.7	Results of the push-off phase	71
3.3.8	Problems detected and their solutions	74
3.4	Second approach to the test methodology	75

3.4.1	Testing frame	75
3.4.2	Restraint frame (Frame 2.0)	75
3.4.3	Numerical behavior of the restraint frame	76
3.4.4	Testing procedures and instrumentation used	78
3.4.5	Second preliminaries tests	80
3.4.6	Final considerations	89
3.5	Final test methodology	90
3.5.1	Testing frame	90
3.5.2	Sliding baseplates	91
3.5.3	New restraint frame	93
3.5.4	Crack width photogrammetry (optional)	97
3.5.5	DEMECT measurements	97
3.5.6	Strain gauges on the external restraint bars	99
3.5.7	Precracking procedure and instrumentation	100
3.5.8	Push-off procedure and instrumentation	100
3.5.9	Experimental results obtained	101
4	Experimental program	103
4.1	Introduction	103
4.2	Experimental outline	104
4.2.1	Study parameters	104
4.2.2	Experimental program	105
4.2.3	Test series	106
4.3	Material properties	109
4.3.1	Mix design	109
4.3.2	Concrete mix procedure	109
4.3.3	Steel fiber	111
4.3.4	Reinforcing steel	111
4.4	Concrete characterization	112
4.4.1	Concrete compressive strength	112
4.4.2	Concrete tensile strength	113

5 Results, analysis and discussions	117
5.1 Introduction	117
5.2 Presentation of the experimental results	118
5.2.1 Results of the precracking phase	118
5.2.2 Comparison between photogrammetry and DEMEC measurements	121
5.2.3 Results of the push-off phase	123
5.3 Study of the restraint frame behavior	126
5.3.1 Real shear stress transmitted by the crack	126
5.3.2 Study of horizontal stiffness of the restraint frame	133
5.3.3 Verification of the ball bearing	137
5.3.4 Statistical study of plate displacements	139
5.4 Analysis and discussion of the experimental program results	143
5.4.1 Influence of w_o	143
5.4.2 Influence of fiber type	145
5.4.3 Influence on amount of fibers	147
5.4.4 Influence of transverse reinforcement (ρ ratio)	149
5.4.5 Influence of concrete strength and maximum aggregate size	151
5.4.6 SFRC and RC comparison	154
5.4.7 Roughness analysis	156
6 Conclusions	163
6.1 Main conclusions	163
6.1.1 About the test methodology	163
6.1.2 Studying the parameters in the experimental program . . .	165
6.2 Recommendations for further research	166
6.2.1 About the methodology	166
6.2.2 About cracked concrete behavior	166
References	168
A Annex A	177