A material-performance-based database for FRC and RC elements under shear loading

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Received: 20 June 2017 / Accepted: 29 December 2017 / Published online: 12 January 2018

Abstract The shear strength of elements reinforced by fibres is predicted by Codes using formulations generally developed from a limited set of test results. In fact, only few of available test results are combined with a material mechanical characterization, allowing to evaluate and compare the different performances of Fibre Reinforced Concretes (FRC). To address this problem, a material-performance-based shear database for FRC elements and their related reference samples in Reinforced Concrete (RC, with and without web reinforcement) is presented herein, merging the experiences carried out in the last decade at the University of Brescia and at the Universitat Politècnica de València. The database is composed by 171 specimens: 93 in FRC and 78 in RC with or without web reinforcement. For FRC elements, the post-cracking resistance ($f_{R,1}$ and $f_{R,3}$) is also given according to EN 14651 standard. The evaluation of the shear database was also carried out, discussing the influence of the different factors affecting the shear strength both in FRC and RC samples. Finally, the two formulations suggested by Model Code 2010 for FRC elements are compared against the database results in order to shed new light on code requirements.

Keywords Steel fibres · Macro-synthetic fibres · Fibre reinforced concrete · Shear · Shear database · Model code 2010

List of symbols

a	Shear span
A_p	Area of prestressing steel
A_s	Longitudinal reinforcement area
b_w	Web width
CMOD	Crack mouth opening displacement

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This is a post-peer-review, pre-copyedit version of an article published in Materials and Structures (2018) 51:11. The final authenticated version is available online at: https://doi.org/10.1617/s11527-017-1130-7

d	Effective depth
d_g	Maximum aggregate size
E_s	Modulus of elasticity of longitudinal reinforcement
E_p	Modulus of elasticity of prestressing steel
f_c	Cylinder compressive concrete strength
f_{ck}	Characteristic value of cylinder compressive concrete strength
f_{ct}	Mean value of tensile concrete strength
f_{Ftu}	Ultimate residual strength according to Model Code 2010
FM	Failure mode (S = shear; SY = shear after longitudinal rebar yielding; WS = web-shear; F = flexure)
$f_{R,1}$	Residual flexural tensile strength corresponding to CMOD = 0.5 mm
$f_{R,3}$	Residual flexural tensile strength corresponding to CMOD = 2.5 mm
M_{Ed}	Applied moment
N_{Ed}	Applied axial force
V_c	Shear strength provided by concrete
$V_{c,F}$	Shear strength provided by fibre reinforced concrete
V_{Ed}	Applied shear force
V_f	Fibre volume fraction
$V_{R,max}$	Shear force at shear compression failure
V_s	Shear strength provided by web reinforcement
V_u	Shear strength
$V_{u,FRC}$	Shear strength of FRC elements
$V_{u,RS}$	Shear strength of reference samples
$V_u/V_{u,code}$	Model safety factor
w_u	Maximum crack opening accepted in structural design
z	Internal lever arm
γ_c	Strength reduction factor according to Eurocode 2 and Model Code 2010
ε_x	Longitudinal strain calculated at mid-depth of d
θ	Angle of inclination of shear cracks
ρ	Longitudinal reinforcement ratio
ρ_w	Web reinforcement ratio
σ_p	Compressive stress due to effective prestress

1 Introduction

The use of fibres as shear reinforcement in Reinforced Concrete (RC) beams was mainly studied during the past three decades, even if the majority of these studied was carried out in the 2000s (Fig. 1). Fibres substantially enhance the shear strength and deformation capacity of structural elements [1, 2] in either vibrated [3–9] or self-compacting concrete [10, 11]; fibres also proved to be very effective in extruded concrete members [12]. Therefore, the effectiveness of fibres in enhancing the shear resistance is widely recognized in the scientific community. So far, the largest number of these studies dealt with steel fibres [3–6, 8–12] even if there was a recent growing interest on macro-synthetic ones [7].

Recent design guidelines allow to use fibres as shear reinforcement [13–15]. RILEM TC 162-TDF [13] proposed pioneer guidelines where fibre contribution to shear resistance was added to the concrete one as a separate term (based on post-cracking residual strengths). In other research studies, fibres and concrete contributions are generally not considered as additional terms since fibres markedly influence the typical mechanisms of shear transfer present in RC element (especially aggregate interlock); Fiber Rein-forced Concrete (FRC) can be considered as a unique composite material characterized by significant tough-ness properties after cracking (due to the bridging effect of fibres). This concept was adopted in the recent Model Code 2010 (hereafter MC2010) [14], where the positive effect of fibres in shear is consid-ered as an enhancement of concrete contribution. The latter was modelled in MC2010 by two different analytical equations (well-discussed in the following sections) based on the post-cracking residual strength provided by FRC, evaluated according to EN 14651 [16]. Consequently, a material mechanical character-ization of FRC is required by MC2010.

Figure 1 shows the number of publications (indexed papers) with experimental results from shear tests on FRC elements in the last 30 years (between 1985 and 2016). It can be observed that the majority of experimental tests (72%) was carried out without providing any FRC mechanical characterization (only fibre type and amount are given), making difficult the use of these results by researchers. Only 28% of papers provides post-cracking mechanical properties of FRC, even if different characterization methods were

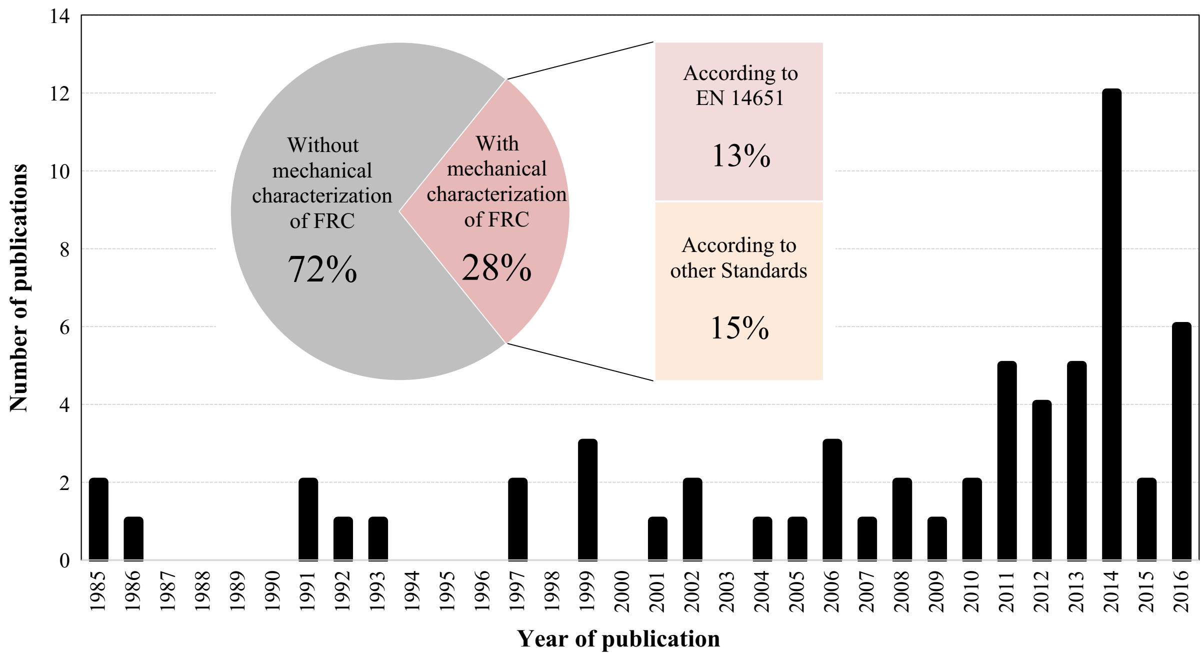

Fig. 1 Papers about shear behaviour on FRC beams

applied. Less than half of them provides a mechanical characterization according to EN 14651 and, so far, only very few recent papers tried to link other tests to EN 14651 [17, 18]. Consequently, shear strength of elements reinforced by fibres is predicted by using formulations generally developed from a limited set of tests results [19, 20] or from literature-derived database [21–24], where most of them do not provide any FRC characterization [21, 22]. In fact, it is very difficult to merge experimental results from different researches when reported data are different [25, 26] or important parameters are not given.

In this context, this paper neither proposes a new formula to add to the already long list nor collects data from other Authors. The objective is to provide a comprehensive shear database to the scientific community, which allows both to improve exiting analytical models and to develop new design formulations in shear. The strength of this database is to have qualified and detailed compilation of data about FRC beams subjected to shear, merging the experiences carried out in the past decades at the University of Brescia and at the Universitat Politècnica de València. The geometry, reinforcement details, post-cracking residual strengths according to EN 14651 ($f_{R,1}$ and $f_{R,3}$) and the experimental results of 93 beams in FRC and their related 78 sample in RC (with or without web reinforcement) are presented. In addition, the database was analysed in order to capture the effect of the typical factors affecting the shear strength in case of FRC beams, as well as to study the increase in shear strength due to fibres addition. The shear formulations of both Eurocode 2 (hereafter EC2) [27] and MC2010 [14] for RC and FRC elements were compared against the database in order to highlight differences and inadequacy on shear strength predictions.

2 Database of FRC elements under shear loading

A comprehensive experimental database involving shear tests on beams reinforced by fibres (either steel and macro-synthetic one) is shown in Table 1. In addition, Table 2 lists the reference samples (RS) in RC made with or without web reinforcement of the beams reported in Table 1, allowing to evaluate the fibres influence on shear strength. This database was compiled from 12 experimental studies performed between 2006 and 2017 at the University of Brescia [28–36] and at the Universitat Politècnica de València [37–39]. The database contains test results of 171

Table 1 Database of FRC elements under shear loading (continued on next page)

Ref	#	Beam ID	b_w (mm)	d (mm)	a/d (−)	ρ (%)	ρ_w (%)	f_c (MPa)	d_g (mm)	σ_p (MPa)	Fibre	V_f (%)	$f_{R,1}$ (MPa)	$f_{R,3}$ (MPa)	*FM*	V_u (kN)
[28]	1	NSC1-FRC1	200	435	2.5	1.04	–	24.8	20	–	S30/0.6H	0.38	2.50	2.40	S	134
	2	NSC1-FRC2	200	435	2.5	1.04	–	24.8	20	–	S30/0.6H + S12/0.18St	0.38 + 0.19	3.41	2.76	F	180
	3	NSC2-FRC1	200	435	2.5	1.04	–	33.5	20	–	S50/1.0H	0.38	2.60	2.29	S	120
	4	NSC2-FRC2	200	435	2.5	1.04	–	33.5	20	–	S50/1.0H + S12/0.18St	0.38 + 0.19	4.01	3.98	S	142
	5	NSC3-FRC1	200	435	2.5	1.04	–	38.6	20	–	S30/0.6H	0.38	3.34	2.73	S	141
	6	HSC-FRC1	200	435	2.5	1.04	–	61.1	15	–	S30/0.62H	0.64	2.90	2.81	S	191
	7	HSC-FRC2	200	435	2.5	1.04	–	58.3	15	–	S30/0.38H	0.64	6.50	5.39	F	223
[29]	8	FRC-20 H50-1	200	455	2.5	0.99	–	24.4	20	–	S50/1.0H	0.25	1.47	1.54	S	154
	9	FRC-20 H50-2	200	455	2.5	0.99	–	24.4	20	–	S50/1.0H	0.25	1.47	1.54	S	194
	10	FRC-40 H50-1	200	455	2.5	0.99	–	20.6	20	–	S50/1.0H	0.51	3.10	2.94	S	125
	11	FRC-40 H50-2	200	455	2.5	0.99	–	20.6	20	–	S50/1.0H	0.51	3.10	2.94	S	133
	12	FRC-60 H50-1	200	455	2.5	0.99	–	19.2	20	–	S50/1.0H	0.76	4.40	4.62	S	211
	13	FRC-60 H50-2	200	455	2.5	0.99	–	19.2	20	–	S50/1.0H	0.76	4.40	4.62	S	199
	14	FRC-20 H100	200	910	2.5	1.04	–	24.4	20	–	S50/1.0H	0.25	1.47	1.54	S	258
[30]	15	FRC-100	200	910	2.5	1.04	–	55.0	20	–	S50/1.0H	0.25	2.47	2.52	S	339
[31]	16	FRC	200	435	3.1	1.56	–	40.7	20	–	S50/1.0H	0.38	2.08	1.91	S	140
	17	ST22-FRC	200	435	3.1	1.56	0.14	45.1	20	–	S50/1.0H	0.38	2.08	1.91	S	168
	18	ST35-FRC	200	435	3.1	1.56	0.25	45.1	20	–	S50/1.0H	0.38	2.08	1.91	F	224
	19	ST45-FRC	200	435	3.1	1.56	0.36	40.7	20	–	S50/1.0H	0.38	2.08	1.91	F	225
	20	ST22-VFRC-a	200	435	3.1	1.56	0.10	41.6	20	–	S50/1.0H	0.38	2.08	1.91	S	163
	21	ST22-VFRC-b	200	435	3.1	1.04	0.10	41.6	20	–	S50/1.0H	0.38	2.08	1.91	F	160
[32]	22	H500 FRC50	250	440	3.0	1.12	–	32.1	16	–	S50/0.8H	0.64	5.40	5.01	SY	240
	23	H500 FRC75	250	440	3.0	1.12	–	33.1	16	–	S50/0.8H	0.96	6.00	6.03	S	235
	24	H1000 FRC50	250	940	3.0	1.07	–	32.1	16	–	S50/0.8H	0.64	5.40	5.01	S	272
	25	H1000 FRC75	250	940	3.0	1.07	–	33.1	16	–	S50/0.8H	0.96	6.00	6.03	S	351
	26	H1500 FRC50	250	1440	3.0	1.01	–	32.1	16	–	S50/0.8H	0.64	5.40	5.01	S	484
	27	H1500 FRC75	250	1440	3.0	1.01	–	33.1	16	–	S50/0.8H	0.96	6.00	6.03	S	554
[33]	28	PFRC 150x600-1	150	563	2.5	1.12	–	34.4	16	–	PP40/0.75C	1.43	2.40	2.58	S	166
	29	PFRC 150x600-2	150	563	2.5	1.12	–	34.4	16	–	PP40/0.75C	1.43	2.40	2.58	S	198
	30	PFRC 150x800-1	150	763	2.5	1.10	–	34.4	16	–	PP40/0.75C	1.43	2.40	2.58	S	205
	31	PFRC 150x800-2	150	763	2.5	1.10	–	34.4	16	–	PP40/0.75C	1.43	2.40	2.58	S	247
	32	PFRC 150x800 PT-1	150	763	2.5	1.10	–	34.4	16	1.30	PP40/0.75C	1.43	2.40	2.58	SY	284

Table 1 continued

Ref	#	Beam ID	b_w (mm)	d (mm)	a/d (–)	ρ (%)	ρ_w (%)	f_c (MPa)	d_g (mm)	σ_p (MPa)	Fibre	V_f (%)	$f_{R,1}$ (MPa)	$f_{R,3}$ (MPa)	*FM*	V_u (kN)
	33	PFRC 300x800-1	300	761	2.5	0.99	–	34.4	16	–	PP40/0.75C	1.43	2.40	2.58	S	381
	34	PFRC 300x800-2	300	761	2.5	0.99	–	34.4	16	–	PP40/0.75C	1.43	2.40	2.58	S	405
[34]	35	W750 FRC25-1	750	210	2.5	1.02	–	38.0	16	–	S50/0.8H	0.32	3.01	2.99	F	356
	36	W750 FRC25-2	750	210	2.5	1.02	–	38.0	16	–	S50/0.8H	0.32	3.01	2.99	F	372
	37	W750 FRC35-1	750	210	2.5	1.02	–	36.9	16	–	S50/0.8H	0.45	3.52	3.62	F	360
	38	W750 FRC35-2	750	210	2.5	1.02	–	36.9	16	–	S50/0.8H	0.45	3.52	3.62	F	370
	39	W1000 FRC25-1	1000	210	2.5	1.05	–	38.0	16	–	S50/0.8H	0.32	3.01	2.99	F	499
	40	W1000 FRC25-2	1000	210	2.5	1.05	–	38.0	16	–	S50/0.8H	0.32	3.01	2.99	F	490
	41	W1000 FRC35-1	1000	210	2.5	1.05	–	36.9	16	–	S50/0.8H	0.45	3.52	3.62	F	490
	42	W1000 FRC35-2	1000	210	2.5	1.05	–	36.9	16	–	S50/0.8H	0.45	3.52	3.62	F	517
[35]	43	W770 PFRC-1	770	255	2.5	1.23	–	26.0	16	–	PP40/0.75C	1.43	2.44	2.99	F	455
	44	W770 PFRC-2	770	255	2.5	1.23	–	26.0	16	–	PP40/0.75C	1.43	2.44	2.99	F	466
	45	W510 PFRC-1	510	255	2.5	1.24	–	26.0	16	–	PP40/0.75C	1.43	2.44	2.99	F	291
	46	W510 PFRC-2	510	255	2.5	1.24	–	26.0	16	–	PP40/0.75C	1.43	2.44	2.99	F	310
	47	W650 PFRC-1	650	215	2.5	1.15	–	26.0	16	–	PP40/0.75C	1.43	2.44	2.99	F	311
	48	W650 PFRC-2	650	215	2.5	1.15	–	26.0	16	–	PP40/0.75C	1.43	2.44	2.99	F	313
	49	W890 PFRC-1	890	295	2.5	1.22	–	26.0	16	–	PP40/0.75C	1.43	2.44	2.99	F	590
	50	W890 PFRC-2	890	295	2.5	1.22	–	26.0	16	–	PP40/0.75C	1.43	2.44	2.99	SY	605
[36]	51	W105 FRC25-14	105	210	2.5	1.40	–	35.3	16	–	S50/0.8H	0.32	2.17	2.23	S	39
	52	W210 FRC25-14	210	210	2.5	1.40	–	35.3	16	–	S50/0.8H	0.32	2.17	2.23	S	98
	53	W315 FRC25-14	315	210	2.5	1.40	–	35.3	16	–	S50/0.8H	0.32	2.17	2.23	S	142
	54	W420 FRC25-14	420	210	2.5	1.40	–	35.3	16	–	S50/0.8H	0.32	2.17	2.23	S	196
	55	W525 FRC25-14	525	210	2.5	1.40	–	35.3	16	–	S50/0.8H	0.32	2.17	2.23	S	261
	56	W630 FRC25-14	630	210	2.5	1.40	–	35.3	16	–	S50/0.8H	0.32	2.17	2.23	S	353
	57	W735 FRC25-14	735	210	2.5	1.40	–	35.3	16	–	S50/0.8H	0.32	2.17	2.23	S	376
[37]	58	H-65/40BN	90	308	2.9	3.72	–	96.0	12	–	S40/0.62H	0.63	6.34	1.30	S	66
	59	M-80/50BN	90	308	2.9	3.72	–	61.9	12	–	S50/0.62H	0.63	7.50	1.83	S	72
	60	H-80/50BN	90	308	2.9	3.72	–	96.3	12	–	S50/0.62H	0.63	6.70	1.91	S	63
	61	L-80/50BN-a	90	308	2.9	3.72	–	34.3	12	–	S50/0.62H	0.63	5.29	3.55	S	60
	62	L-65/40BN	90	308	2.9	3.72	–	33.8	12	–	S40/0.62H	0.63	5.45	3.69	S	57
	63	M-45/50BN	90	308	2.9	3.72	–	51.0	12	–	S50/1.05H	0.63	4.18	4.43	S	67

Table 1 continued

Ref	#	Beam ID	b_w (mm)	d (mm)	a/d (−)	ρ (%)	ρ_w (%)	f_c (MPa)	d_g (mm)	σ_p (MPa)	Fibre	V_f (%)	$f_{R,1}$ (MPa)	$f_{R,3}$ (MPa)	*FM*	V_u (kN)
	64	M-65/40BN-a	90	308	2.9	3.72	–	66.6	12	–	S40/0.62H	0.63	6.48	4.50	S	75
	65	M-80/30BP	90	308	2.9	3.72	–	49.7	12	–	S30/0.38H	0.63	6.93	7.13	S	93
	66	H-80/30BP	90	308	2.9	3.72	–	83.6	12	–	S30/0.38H	0.63	8.84	7.38	S	95
	67	L-80/40BP	90	308	2.9	3.72	–	40.7	12	–	S40/0.5H	0.63	7.71	8.18	S	81
	68	M-80/40BP	90	308	2.9	3.72	–	71.1	12	–	S40/0.5H	0.63	8.16	9.44	S	101
	69	H-80/40BP	90	308	2.9	3.72	–	88.1	12	–	S40/0.5H	0.63	12.20	10.60	S	112
[38]	70	HF400 h/6	100	739	2.8	1.71	–	64.5	12	8.46	S40/0.62H	0.75	8.96	5.96	WS	420
	71	HF600/4	100	689	3.0	1.83	–	64.5	12	8.46	S40/0.62H	0.75	10.46	6.24	WS	392
	72	HF600/5	100	689	3.0	1.83	–	64.5	12	8.46	S40/0.62H	0.75	8.55	5.55	WS	347
	73	HF400/7	100	689	3.0	1.83	–	64.5	12	9.41	S40/0.62H	0.75	6.64	4.77	WS	390
	74	HF400/8	100	689	3.0	1.83	–	64.5	12	9.41	S40/0.62H	0.75	8.10	4.68	WS	428
	75	HF260/9	100	689	3.0	1.83	–	64.5	12	10.36	S40/0.62H	0.75	6.45	5.68	WS	326
	76	HF600/1	100	689	3.0	1.83	0.34	64.5	12	8.46	S40/0.62H	0.75	5.26	5.13	WS	572
	77	HF600/2	100	689	3.0	1.83	0.34	64.5	12	8.46	S40/0.62H	0.75	9.36	6.89	WS	593
[39]	78	OAS1	305	470	3.9	1.70	–	39.7	16	–	S60/0.9H	0.38	3.22	4.12	S	233
	79	OAS2	305	469	4.9	2.30	–	39.7	16	–	S60/0.9H	0.38	3.22	4.12	S	228
	80	OBS1	229	472	3.9	2.20	–	39.7	16	–	S60/0.9H	0.38	3.22	4.12	S	155
	81	OBS2	229	469	4.9	2.30	–	39.7	16	–	S60/0.9H	0.38	3.22	4.12	S	163
	82	AS1	305	477	3.8	1.70	0.10	39.7	16	–	S60/0.9H	0.38	3.22	4.12	SY	335
	83	AS2	305	477	4.8	2.20	0.10	39.7	16	–	S60/0.9H	0.38	3.22	4.12	SY	329
	84	BS1	229	477	3.8	2.20	0.15	39.7	16	–	S60/0.9H	0.38	3.22	4.12	S	273
	85	BS2	229	475	4.8	2.20	0.15	39.7	16	–	S60/0.9H	0.38	3.22	4.12	S	246
	86	OAP1	305	473	3.9	1.70	–	43.6	16	–	PP48/0.85C	1.10	2.78	4.30	S	223
	87	OAP2	305	473	4.8	2.20	–	43.6	16	–	PP48/0.85C	1.10	2.78	4.30	S	243
	88	OBP1	229	471	3.9	2.20	–	43.6	16	–	PP48/0.85C	1.10	2.78	4.30	S	181
	89	OBP2	229	469	4.9	2.20	–	43.6	16	–	PP48/0.85C	1.10	2.78	4.30	S	148
	90	AP1	305	475	3.9	1.70	0.10	43.6	16	–	PP48/0.85C	1.10	2.78	4.30	SY	348
	91	AP2	305	474	4.8	2.20	0.10	43.6	16	–	PP48/0.85C	1.10	2.78	4.30	S	339
	92	BP1	229	481	3.8	2.20	0.15	43.6	16	–	PP48/0.85C	1.10	2.78	4.30	S	278
	93	BP2	229	475	4.8	2.20	0.15	43.6	16	–	PP48/0.85C	1.10	2.78	4.30	SY	244

Table 2 Database of reference samples in RC (continued on next page)

Ref	#	Beam ID	b_w (mm)	d (mm)	a/d (−)	ρ (%)	ρ_w (%)	f_c (MPa)	d_g (mm)	σ_p (MPa)	FM	V_u (kN)
[28]	94	NSC1-PC	200	435	2.5	1.04	–	24.8	20	–	S	69
	95	NSC2-PC	200	435	2.5	1.04	–	33.5	20	–	S	84
	96	NSC3-PC	200	435	2.5	1.04	–	38.6	20	–	S	83
	97	HSC-PC	200	435	2.5	1.04	–	60.5	15	–	S	113
[29]	98	PC H50-1	200	455	2.5	0.99	–	25.9	20	–	S	105
	99	PC H50-2	200	455	2.5	0.99	–	25.9	20	–	S	110
	100	MSR H50-1	200	455	2.5	0.99	0.17	25.9	20	–	S	170
	101	MSR H50-2	200	455	2.5	0.99	0.17	25.9	20	–	S	153
	102	PC H100	200	910	2.5	1.04	–	25.9	20	–	S	194
	103	MSR H100	200	910	2.5	1.04	0.08	25.9	20	–	S	329
[30]	104	PC-100	200	910	2.5	1.04	–	55.0	20	–	S	208
[31]	105	PC	200	435	3.1	1.56	–	44.0	20	–	S	103
	106	ST22	200	435	3.1	1.56	0.14	40.3	20	–	S	171
	107	ST35	200	435	3.1	1.56	0.25	40.3	20	–	S	209
	108	ST45	200	435	3.1	1.56	0.36	44.0	20	–	F	220
[32]	109	H500 PC	250	440	3.0	1.12	–	38.7	16	–	S	116
	110	H1000 PC	250	940	3.0	1.07	–	38.7	16	–	S	188
	111	H1500 PC	250	1440	3.0	1.01	–	38.7	16	–	S	211
[33]	112	PC 150x600-1	150	563	2.5	1.12	–	30.4	16	–	S	89
	113	PC 150x600-2	150	563	2.5	1.12	–	30.4	16	–	S	64
	114	MSR 150x600-1	150	563	2.5	1.12	0.32	30.4	16	–	F	185
	115	MSR 150x600-2	150	563	2.5	1.12	0.32	30.4	16	–	F	204
	116	PC 150x800-1	150	763	2.5	1.10	–	30.4	16	–	S	91
	117	PC 150x800-2	150	763	2.5	1.10	–	30.4	16	–	S	101
	118	MSR 150x800-1	150	763	2.5	1.10	0.32	30.4	16	–	F	244
	119	MSR 150x800-2	150	763	2.5	1.10	0.32	30.4	16	–	F	250
	120	PC 150x800 PT-1	150	763	2.5	1.10	–	30.4	16	1.30	S	199
	121	PC 300x800-1	300	761	2.5	0.99	–	30.4	16	–	S	183
	122	MSR 300x800-1	300	761	2.5	0.99	0.16	30.4	16	–	F	424
	123	MSR 300x800-2	300	761	2.5	0.99	0.16	30.4	16	–	F	436
[34]	124	W750 PC-1	750	210	2.5	1.02	–	40.5	16	–	S	238
	125	W750 MSR-1	750	210	2.5	1.02	0.10	40.5	16	–	F	335
	126	W750 MSR-2	750	210	2.5	1.02	0.10	40.5	16	–	F	338
	127	W1000 PC-1	1000	210	2.5	1.05	–	40.5	16	–	S	338
	128	W1000 PC-2	1000	210	2.5	1.05	–	40.5	16	–	S	311
	129	W1000 MSR-1	1000	210	2.5	1.05	0.11	40.5	16	–	F	465
	130	W1000 MSR-2	1000	210	2.5	1.05	0.11	40.5	16	–	F	442
[35]	131	W430 PC-1	430	215	2.5	1.30	–	31.2	16	–	S	170
	132	W430 PC-2	430	215	2.5	1.30	–	31.2	16	–	S	177
	133	W770 PC-1	770	255	2.5	1.23	–	31.2	16	–	S	338
	134	W770 PC-2	770	255	2.5	1.23	–	31.2	16	–	S	337
	135	W770 MSR-1	770	255	2.5	1.23	0.10	31.2	16	–	F	468
	136	W770 MSR-2	770	255	2.5	1.23	0.10	31.2	16	–	F	462

Table 2 continued

Ref	#	Beam ID	b_w (mm)	d (mm)	a/d (−)	ρ (%)	ρ_w (%)	f_c (MPa)	d_g (mm)	σ_p (MPa)	FM	V_u (kN)
[36]	137	W105 PC-14	105	210	2.5	1.40	–	40.4	16	–	S	26
	138	W210 PC-14	210	210	2.5	1.40	–	40.4	16	–	S	64
	139	W315 PC-14	315	210	2.5	1.40	–	40.4	16	–	S	97
	140	W420 PC-14	420	210	2.5	1.40	–	40.4	16	–	S	157
	141	W525 PC-14	525	210	2.5	1.40	–	40.4	16	–	S	173
	142	W630 PC-14	630	210	2.5	1.40	–	40.4	16	–	S	204
	143	W735 PC-14	735	210	2.5	1.40	–	40.4	16	–	S	242
	144	W105 PC-20	105	210	2.5	1.42	–	39.3	16	–	S	28
	145	W210 PC-20	210	210	2.5	1.42	–	39.3	16	–	S	53
	146	W315 PC-20	315	210	2.5	1.42	–	39.3	16	–	S	89
	147	W420 PC-20	420	210	2.5	1.42	–	39.3	16	–	S	121
	148	W525 PC-20	525	210	2.5	1.42	–	39.3	16	–	S	153
	149	W630 PC-20	630	210	2.5	1.42	–	39.3	16	–	S	204
	150	W735 PC-20	735	210	2.5	1.42	–	39.3	16	–	S	243
	151	W315 PC-24	315	210	2.5	1.37	–	39.3	16	–	S	102
	152	W630 PC-24	630	210	2.5	1.37	–	39.3	16	–	S	190
	153	W735 PC-24	735	210	2.5	1.46	–	39.3	16	–	S	240
[37]	154	M-0	90	308	2.9	3.72	–	50.5	12	–	S	38
	155	H-0	90	308	2.9	3.72	–	85.6	12	–	S	40
	156	M-Φ6	90	308	2.9	3.72	0.16	48.3	12	–	S	74
	157	H-Φ6	90	298	3.0	3.84	0.16	74.5	12	–	S	79
	158	L-Φ6	90	298	3.0	3.84	0.16	41.9	12	–	S	86
	159	A	200	650	3.2	3.02	0.17	50.5	16	–	S	358
	160	B	200	650	3.2	3.02	0.17	53.8	16	–	S	365
	161	M-Φ8	90	308	2.9	3.72	0.37	50.5	12	–	S	81
	162	H-Φ8	90	308	2.9	3.72	0.37	85.6	12	–	S	94
[38]	163	H600/3	100	689	3.0	1.83	0.34	64.5	12	8.46	WS	491
[39]	164	OA1	305	473	3.9	1.70	–	40.6	16	–	S	156
	165	OA2	305	474	4.8	2.20	–	40.6	16	–	S	169
	166	OB1	229	473	3.9	2.20	–	40.6	16	–	S	137
	167	OB2	229	471	4.8	2.20	–	40.6	16	–	S	113
	168	A1	305	473	3.9	1.70	0.10	40.6	16	–	S	236
	169	A2	305	473	4.8	2.20	0.10	40.6	16	–	S	239
	170	B1	229	474	3.9	2.20	0.15	40.6	16	–	S	234
	171	B2	229	474	4.8	2.20	0.15	40.6	16	–	S	220

beams (117 and 54 tested at the University of Brescia and Universitat Politècnica de València, respectively), where 93 are made with FRC (Table 1) and 78 are in RC made with or without web reinforcement (Table 2). The majority of the beams exhibited either a shear or web-shear failure mode. In case of FRC samples, 73 beams failed in shear and 20 in flexure, while for RC beams 65 exhibited a shear failure and 13 a flexure one. All members failing in flexure are anyway reported in this database since they might give data for further specific analysis and applications. However, these samples were not considered in the database analyses presented in Sect. 3. It should be also noticed that 9 FRC beams (over 93) and 2 RC beams (over 78) of database are prestressed.

For the collection of a consistent and comprehensive database, the following parameters are showed for each beam:

- order number (#);
- beam ID;
- web width (b_w);
- effective depth (d);
- shear span to effective depth ratio (a/d);
- longitudinal reinforcement ratio (ρ);
- web reinforcement ratio (ρ_w);
- cylinder concrete compressive strength (f_c);
- maximum aggregate size (d_g);
- compressive stress due to effective prestress (σ_p);
- fibre type in terms of: material (S = steel, PP = polypropylene), length in mm/diameter in mm, shape (H = hooked ends, St = straight, C = crimped). As an example, the designation S30/0.6H refers to a steel fibres 30 mm long, with diameter of 0.6 mm and hooked ends.
- fibres volume fraction (V_f);
- residual flexural tensile strengths $f_{R,1}$ and $f_{R,3}$ (in accordance to EN 14651 [16]) corresponding to CMOD = 0.5 mm and CMOD = 2.5 mm, respectively;
- failure mode (FM): S = shear; SY = shear after longitudinal rebar yielding; WS = web-shear, namely the failure due to diagonal tension developed before flexural cracking; F = flexure;
- experimental shear strength (V_u).

The cross section of beams in this shear database is rectangular, except for samples in Refs. [37] and [38] that are characterized by I-shape. More details about flange dimensions can be found in [37] and [38], as well as in Ref. [11] a deep analysis on samples from 58 to 69 is given. Moreover, it is worth mentioning that both longitudinal and web reinforcement adopted in the database are made with the steel most commonly used in Europe, i.e. B500C [27].

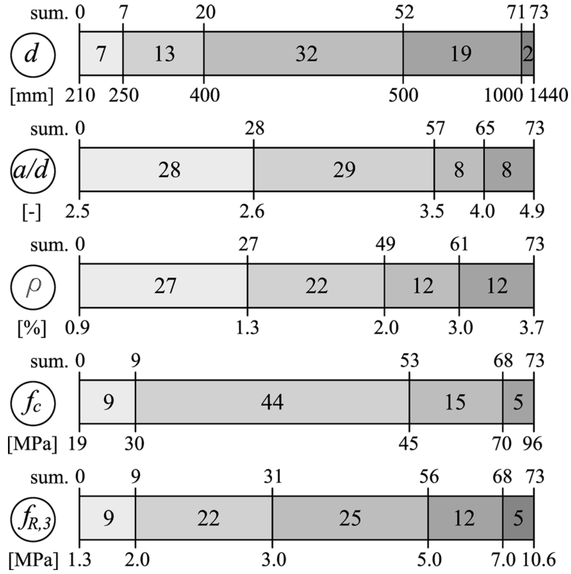

Fig. 2 Distribution of parameters in the shear database for FRC elements (only shear failure)

3 Evaluation of the shear database

Figure 2 shows the distribution of the main parameters affecting the shear strength in the database considering the 73 specimens failed in shear. It can be observed that wide ranges of selected parameters are considered. d varies from 210 to 1440 mm with 70% of beams under 500 mm, while a/d ratio ranges from 2.5 to 3.5 for the majority of samples (80%). Typical ρ adopted in practice (up to 1.3%) can be observed for 40% of samples, while, in order to induce a shear failure, higher amount of longitudinal reinforcement was used elsewhere (up to 3.7%). Different concrete compressive classes were also studied, with f_c ranging from 19 to 96 MPa (with 70% of samples character-ized by a f_c smaller than 45 MPa). Finally, the database incorporate FRCs characterized by a signif-icantly wide range of residual mechanical properties (both softening and hardening materials under flex-ure): $f_{R,3}$ varying from 1.3 to 10.6 MPa. In particular, 31 samples have a $f_{R,3}$ smaller than 3.0, followed by 25 specimens in the range between 3 and 5 MPa and the remaining 17 beams with higher residual mechanical properties.

In these parameter ranges, the increase in shear strength due to fibre addition was analysed by comparing each FRC beam (fibre only, Table 1) to its reference sample (without web reinforcement, Table 2). In particular, the ratio between the shear strength of FRC beams ($V_{u,FRC}$) and the one of their reference samples ($V_{u,RS}$) was calculated and plotted as a function of $f_{R,3}$ in Fig. 3. This allows to obtain the fibre contribution on shear strength, excluding the influence of all other affecting parameter (i.e. d, a/d, ρ, f_c), which are equal between each FRC sample and its corresponding reference specimen. $f_{R,3}$ was chosen

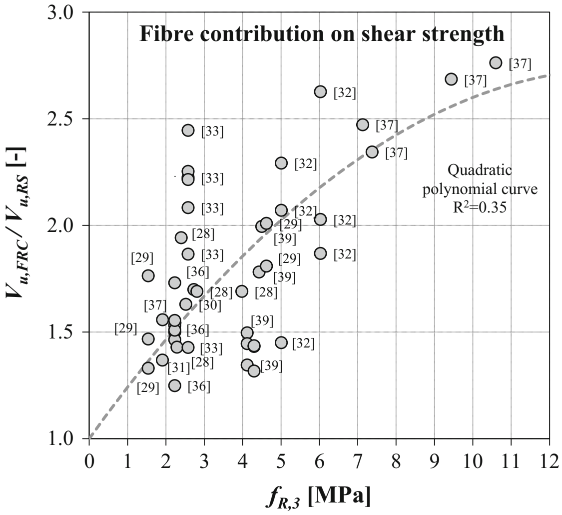

Fig. 3 Increase in shear strength due to effect of fibres

since it characterizes the post-cracking performance given by different fibres (which differ in length, shape, material and amount) at ultimate limit state. Figure 3 clearly shows that an increase of $f_{R,3}$ determines a significant increment of shear strength, resulting in a rather fundamental tool for engineers for both pre-design and verification phases against shear loading. For instance, a $f_{R,3}$ of 2 and 5 MPa lead to a shear strength increment of about 50 and 100%, respectively. The parameter $f_{R,3}$ was related to shear strength increment by using the method of least squares (imposing an intercept $V_{u,FRC}/V_{u,RS} = 1$ for $f_{R,3} = 0$) and it was observed that the best trend is a quadratic regression, even if it is characterized by a weak coefficient of determination ($R^2 = 0.35$). The latter is due to the fact that for a given $f_{R,3}$ the ratio $V_{u,FRC}/V_{u,RS}$ showed a variability, as a consequence of the combined effect of both $f_{R,3}$ (coefficient of variations ranging between 10 and 40% [40]) variability and shear strength dispersion (placing, compaction, beam geometry and fibre type can influence fibre distribution and orientation [41]). Moreover, the load at which the inclined shear cracking occurs is a function of the tensile strength of concrete, which in turn is a quite disperse material property. This also contributes, with the other factors as above-men-tioned, to the shear strength variability of elements reinforced by fibres only.

The influence of fibres on well-known parameters affecting the shear strength was evaluated as well. In particular, Fig. 4 shows the influence of fibres on the shear strength as a function of effective depth (Fig. 4a) and longitudinal reinforcement ratio (Fig. 4b). In this figure, the normalized shear strength ($v_u/f_c^{(1/2)}$) is plotted as a function of the two parameters; moreover, FRC specimens were separated in three $f_{R,3}$ ranges. It can be observed that, as already stated by Minelli et al. [32] and Shoaib et al. [6], the database confirms that FRC beams are affected by size effect (Fig. 4a). This influence is similar to RC beams without web reinforcement up to an effective depth of 1000 mm, after which the trend of the size effect law for FRC

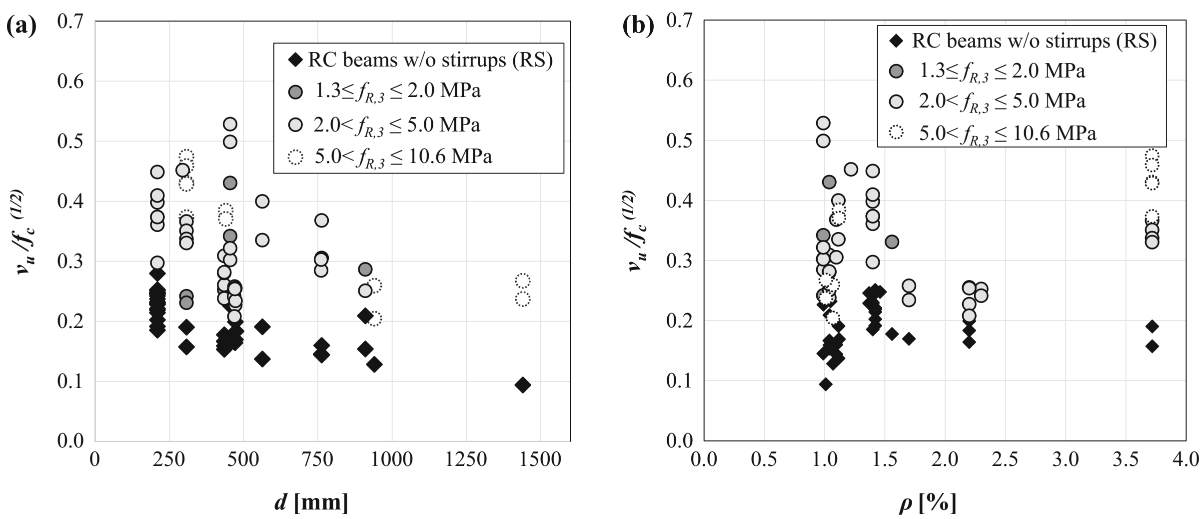

Fig. 4 Size effect trend for RC and FRC elements (**a**) and effect of fibres as the reinforcement ratio increases (**b**)

differs and it seems that a lower bound is reached (horizontal asymptote). Comparing the three performance ranges shown in Fig. 4a, it can be also observed that the decrease in the shear at failure is similar up to 1000 mm, underlining that the post-cracking performance of FRC does not significantly change the size effect law. Consequently, building codes could consider this positive effect of fibres in beams characterized by effective depth greater than 1000 mm, while classical RC size effect law can be applied for FRC elements with $d \leq 1000$ mm. When considering the longitudinal reinforcement ratio, an increment of ρ causes a similar increase of ultimate shear strength in both RC and FRC elements, even for higher values of $f_{R,3}$. This trend is also similar between the different FRC considered. Therefore, the longitudinal reinforcement influence on the shear strength seems not to clearly change from RC to FRC elements and its effects are comparable. The positive influence on the shear strength of the longitudinal reinforcement ratio is due to the increase in crack width for ρ reduction that causes a decrease in the shear transferred across the inclined crack by dowel action and aggregate interlock. Similarly to ρ, either f_c or *a/d* influence resulted comparable both in RC and FRC samples. These database analysis underline that fibres mainly increase the shear strength of elements by transferring stresses across inclined shear cracks and by enhancing aggregate interlock mechanism [42–44].

4 Comparison with design equations of EC2 and MC2010

The shear strength predictions of two different analytical models recently included in MC2010 and developed for FRC beams were evaluated against the experimental results presented in the database. In addition, the provisions of their base models were also analysed against the reference samples listed in Table 2. In order to make this comparison more significant, the shear strength were calculated by assuming strength reduction factors (γ_c for EC2 and MC2010) equal to 1 and the mean values of the material mechanical properties. The mean value of tensile strength f_{ct} was evaluated according to Eq. 5.1-3a ($f_{ct} = 0.3 \cdot (f_{ck})^{2/3}$) and 5.1-3b ($f_{ct} = 2.12 \cdot \ln[1 + 0.1 \cdot (f_{ck} + 8\text{ MPa})]$) of MC2010 for concrete characterized by $f_{ck} \leq 50$ MPa and $f_{ck} > 50$ MPa, respectively. The characteristic value of the concrete compressive strength was calculated as $f_{ck} = f_c - 8$ MPa according to Eq. 5.1-1 of MC2010. In case of MC2010 shear models, when required, the control section was considered at a location d from load point.

Table 3 summarize the shear formulations of these models for the prediction of the shear strength resistance (express in terms of SI units). Concerning FRC, the first model (Eq. (5) in Table 3) was built on the base formulation of EC2 (Eq. (1) in Table 3) [45] and it considers the fibre contribution by modifying the longitudinal reinforcement ratio. To the contrary, the second one (Eq. (7) in Table 3) was derived from the base formulation of MC2010 (Eq. (3) in Table 3) [46], which in turn is linked to the Modified Compression Field Theory [47]. Both formulations consider the fibre contribution not as a separate addendum but as an enhancement of the concrete contribution, as well as they adopt an ultimate residual tensile strength (f_{Ftu}). In case of Eq. (5), MC2010 suggests to estimate f_{Ftu} by a simplified linear model based on $f_{R,1}$ and $f_{R,3}$ (EN 14651), while in case of Eq. (7) it is suggested to evaluate it by direct tensile tests (without specifying the type of tensile tests). Since no direct tensile tests were carried out for any of the database series, the simplified linear model based on $f_{R,1}$ and $f_{R,3}$ (EN 14651) has been also applied in case of Eq. (7). Recent publications discussed also the possible influence of using the simplified linear model ($f_{R,1}$ and $f_{R,3}$) on Eq. (7) [17, 48]. Amin et al. [17] studying steel FRC showed that that MC2010 simplified linear model might overestimate f_{Ftu}, with direct consequence on the accuracy of the shear model [48]. Consequently, it should be noticed that the evaluation of Eq. (7) against database results could be also affected by the use of the simplified linear model for estimating f_{Ftu}.

Figure 5 shows the comparison between the experimental and the ultimate shear strength predicted by the base models of EC2 (Eq. (1)) and MC2010 II level (Eq. (3)) for RC elements without web reinforcement. In this figure, specimens were ordered by increasing effective depth. It can be observed that both base models lead to good and very similar strength predictions. The mean value of the model safety factor $V_u/V_{u,code}$ resulted in both case greater than the unity, i.e. 1.08 and 1.10 for EC2 and MC2010 model with coefficient of variation equal to 0.19. This

Table 3 Design equations for the shear strength resistance of RC elements with and w/o fibres according to MC2010 [14] and EC2 [27]

RC elements		
EC2	$V_c = \left(0.18 \cdot k \cdot (100 \cdot \rho \cdot f_c)^{1/3} + 0.15 \cdot \sigma_p\right) \cdot b_w \cdot d$	Eq. (1)
	$V_s = A_s/s \cdot f_y \cdot z \cdot \cot\theta$ with $21.8° \leq \theta \leq 45°$	Eq. (2)
	$k = 1 + \sqrt{200/d} \leq 2$	
	$\rho \leq 0.02$	
MC2010	$V_c = k_v \cdot \sqrt{f_c} \cdot b_w \cdot z$	Eq. (3)
	$V_s = A_s/s \cdot f_y \cdot z \cdot \cot\theta$	Eq. (4)
	$k_v = 0.4/(1 + 1500\varepsilon_x) \cdot \left(1300/\left(1000 + k_{dg} \cdot z\right)\right)$	
	$k_v = 0.4/(1 + 1500\varepsilon_x) \cdot \left(1 - V_{Ed}/V_{R,max}\right)$	
	$\theta = 20° + 10000\varepsilon_x$	
FRC elements		
MC2010	$V_{c,F} = \left(0.18 \cdot k \cdot (100 \cdot \rho \cdot (1 + 7.5 f_{Ftu}/f_{ct}) \cdot f_c)^{1/3} + 0.15 \cdot \sigma_p\right) \cdot b_w \cdot d$	Eq. (5)
	$V_s = A_s/s \cdot f_y \cdot z$	Eq. (6)
	$k = 1 + \sqrt{200/d} \leq 2$	
	$\rho \leq 0.02$	
	$w_u = 1.5$ mm	
	$V_{c,F} = (k_v \cdot \sqrt{f_c} + 0.8 \cdot f_{Ftu} \cdot \cot\theta) \cdot b_w \cdot z$	Eq. (7)
	$V_s = A_s/s \cdot f_y \cdot z \cdot \cot\theta$	Eq. (8)
	$k_v = 0.4/(1 + 1500\varepsilon_x) \cdot \left(1300/\left(1000 + k_{dg} \cdot z\right)\right)$	
	$k_{dg} = 32/\left(16 + d_g\right) \geq 0.75$	
	$\theta = 29° + 7000\varepsilon_x$	
	$w_u = 0.2 + 1000\varepsilon_x \geq 0.125$ mm	

$\varepsilon_x = \frac{1}{2 \cdot E_s \cdot A_s} \cdot \left[\frac{M_{Ed}}{z} + V_{Ed} + N_{Ed} \cdot \left(\frac{1}{2} \mp \frac{\Delta e}{z}\right)\right]$ according to Eq. 7.3-16 of MC2010

$\varepsilon_x = \left[\frac{M_{Ed}}{z} + V_{Ed} + N_{Ed} \cdot \frac{(z_p - e_p)}{z}\right] / \left[2 \cdot \left(\frac{z_s}{z} \cdot E_s \cdot A_s + \frac{z_p}{z} \cdot E_p \cdot A_p\right)\right] \geq 0$ for prestressed members according to Eq. 7.3-14 of MC2010

$f_{Ftu} = 0.45 \cdot f_{R1} - \frac{w_u}{2.5\ \text{mm}} \cdot (0.45 \cdot f_{R1} - 0.5 \cdot f_{R3} + 0.2 \cdot f_{R1}) \geq 0$ according to Eq. 5.6-6 of MC2010

confirms that both models are comparable, as well as they are mainly characterized by conservative or slightly unconservative predictions. In addition, it is worth mentioning that both models show a decrement of the ratio $V_u/V_{u,code}$ when the effective depth increase: for d up to 250 mm this ratio is generally greater than 1, for $250 < d \leq 1000$ mm is around 1, while it is smaller than 1 (unconservative) for $d > 1000$ mm. Even if for d greater than 1000 mm only one samples is present in the database (H1500 PC), this general downward trend of $V_u/V_{u,code}$ is clearly evident; this result underlines that EC2 and MC2010 could better take into account size effect in shear resistance of RC beams. To the contrary, no clear trend of $V_u/V_{u,code}$ was observed varying ρ, a/d or f_c. It is worth mentioning that both EC2 and MC2010 models resulted even more conservative in case of wide-shallow beams (W750 PC-1, W1000 PC-1 and 2, W430 PC-1 and 2, W770 PC-1 and 2) due also to the positive effect of width-to-effective depth ratio. More details about width-to-effective depth ratio influence on the shear strength can be found in [36].

Likewise Figs. 5 and 6 shows the predictions of both EC2 [Eq. (1) + Eq. (2)] and MC2010 III level [Eq. (3) + Eq. (4)] model for beams with web reinforcement. In case of EC2 model, the shear strength was assumed as the sum of V_c and V_s with $\theta = 45°$. It can be observed that, once again, both models are very

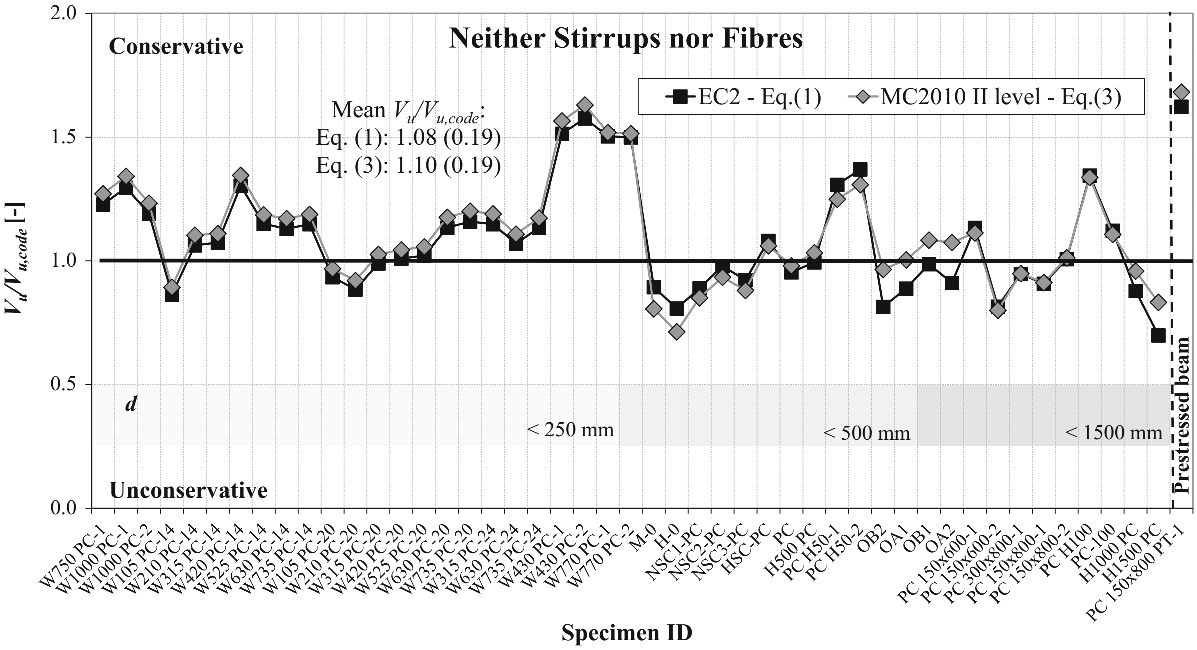

Fig. 5 Comparison against EC2 and Model Code 2010 shear model for beams without web reinforcement

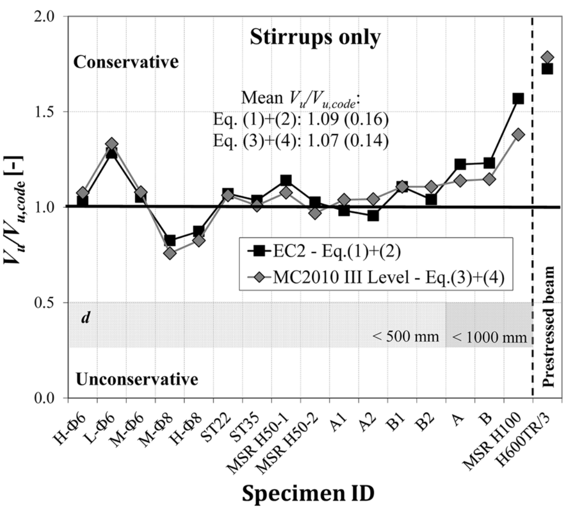

Fig. 6 Comparison against EC2 and Model Code 2010 shear model for beams with web reinforcement

similar and lead to good provisions, as well as they are generally conservative and characterized by a mean value of $V_u/V_{u,code}$ close to 1.10. The prediction variability is 25% smaller as compared to beams without web reinforcement, as evidenced by the coefficient of variations. In addition, no variation of the ratio $V_u/V_{u,code}$ is remarkable by varying d, ρ, a/d or f_c increases.

Figure 7 shows the comparison between V_u and $V_{u,code}$ predicted by the two different shear formulations of MC2010 [Eqs. (5) and (7)] for elements with fibre only as shear reinforcement. In this figure, specimens were ordered by increasing the residual strength $f_{R,3}$. It can be observed that Eq. (5) is characterized by a similar value of $V_u/V_{u,code}$ as compared to its base model [Eq. (1)], even if the variability is 15% greater. To the contrary, Eq. (7) accuracy differs from the one of base model as demonstrated by the mean value of $V_u/V_{u,code}$, often smaller than 1, and by the greater coefficient of variation (+ 27%). Consequently, Eq. (7) leads to more variable and unconservative predictions than Eq. (5). In addition, it should be noticed that both models reduce their level of safety when $f_{R,3}$ increases. In fact, for $f_{R,3} > 3$ MPa the ratio $V_u/V_{u,code}$ resulted closer or even smaller than 1 as compared to samples with $f_{R,3} \leq 3$. This underlines that both models require some modifications in order to better capture the increment of shear strength due to the effect of fibres. The reduction of the ratio $V_u/V_{u,code}$ when the effective depth increase is also present as in the base models, even if, for d greater than 1000 mm, Eq. (7) resulted

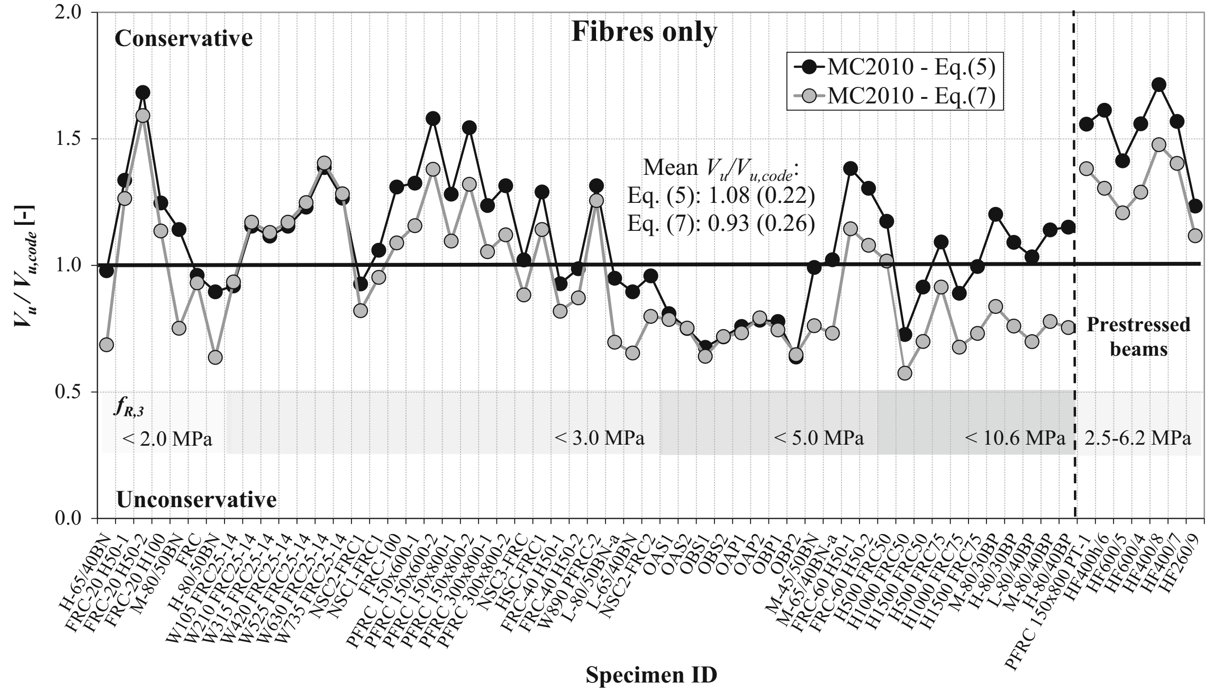

Fig. 7 Comparison against Model Code 2010 shear models for beams reinforced by fibres only

more unconservative than Eq. (5) (see samples H1500 FRC50 and H1500 FRC75 in Fig. 7). Equation (7) led also to more unconservative predictions for $\rho > 0.02$ and $f_c > 70$ MPa, while Eq. (5) does not provide significant variation of $V_u/V_{u,code}$ with increasing values of ρ or f_c. However, it is should be noticed that, in Eq. (5), the shear strength is predicted by imposing a limitation on the longitudinal reinforce-ment ratio as in the base model, i.e. $\rho \leq 0.02$. No influence of *a/d* was observed in both models.

Figure 8 shows the shear strength predictions of the two models [either Eq. (5) + Eq. (6) with $\theta = 45°$ or Eq. (7) + Eq. (8)] in case of combination of fibres and web reinforcement. It can be observed that both models resulted comparable and always unconservative; the mean value of $V_u/V_{u,code}$ was of around 0.88 with a low CV. This evidence underlines that both models probably require modifications for improve their predictions in case of elements reinforced by both fibres and web reinforcement. However, since the available data concerning beams reinforced by both fibres and stirrups are limited (10 samples), further specific experiments should be carried out in order to confirm this model inadequacy.

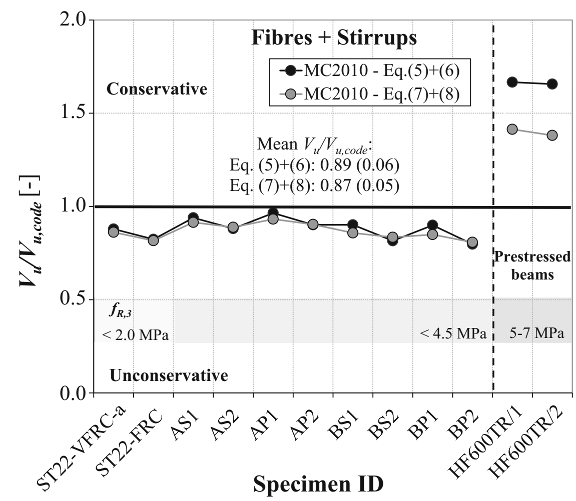

Fig. 8 Comparison against Model Code 2010 shear models for beams reinforced by both fibres and web reinforcement

Finally, it can be underlined that, in case of prestressed elements, the equations listed in Table 3 are always conservative both in RC (Figs. 5, 6) and FRC elements (Figs. 7, 8). However, it should be reminded that only few prestressed specimens are available and the majority of them showed a web-shear failure.

5 Concluding remarks

Experimental tests on RC and FRC elements carried out in the last decade at both the University of Brescia and the Universitat Politècnica de València were collected and analysed in the present paper. The following conclusions might be drawn:

(1) A comprehensive shear database of 171 elements (93 in FRC and their related 78 reference samples in RC with or without web reinforcement) is presented, defining the principal variables (d, a/d, ρ, ρ_w, f_c, d_g, σ_p) and the residual mechanical properties of FRC: $f_{R,1}$ and $f_{R,3}$. This database will allow further development and validation of suitable shear strength formulations for FRC elements;

(2) a/d, ρ, and f_c (related to tensile strength) similarly influence the shear strength both in RC and FRC elements. Instead, the beam size influence is different for $d > 1000$ mm since the horizontal asymptote is reached earlier in FRC members (for $d \leq 1000$ mm classical RC size effect law can be applied also for FRC elements);

(3) EC2 and MC2010 shear formulations lead to similar and good predictions of the shear resistance of RC elements with or without web reinforcement;

(4) The two shear models provided by MC2010 (f_{Ftu} evaluated in both models according to MC2010 linear model, even if direct tensile tests are suggested by MC2010 for Eq. (7)) for elements reinforced by fibre only reduce their level of safety when $f_{R,3}$ increases. In fact, for $f_{R,3} > 3$ MPa the model safety factor ($V_u/V_{u,code}$) resulted closer or even smaller than 1, as compared to samples with $f_{R,3} \leq 3$;

(5) The FRC shear strength equation of MC2010 based on EC2 model (Eq. 5 in Table 3) resulted more conservative than the one developed on the Modified Compression Field Theory (Eq. 7 in Table 3 with the assumption of evaluating f_{Ftu} from the MC2010 linear model). In partic-ular, they mainly differ for specimens with $d > 1000$ mm, $\rho > 0.02$ and $f_c > 70$ MPa.

(6) The shear strength of elements reinforced by a combination of fibres and web reinforcement seems not to be well predicted by MC2010.

The Authors would like also to encourage all researchers to provide in their future works at least the information reported in the database in order to allow its extension. The results of FRC characterization tests are, with this respect, very important and needful.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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