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Bond of Epoxy-Coated Reinforcement: Coefficient of Friction and Rib Face Angle

by Emmanuel K. Idun and David Darwin

The coefficients of friction between epoxy-coated and uncoated reinforcing steel and mortar and the effects of rib face angle on the relative bond strength of epoxy-coated bars are determined. Results for 130 test specimens indicate that the average coefficient of friction is about 0.49 between epoxy-coated reinforcing steel and mortar and about 0.56 between uncoated reinforcing steel and mortar. Based on 58 beam-end specimen tests using both machined and rolled 1-in. (25-mm) nominal diameter reinforcing bars with face angles of 30, 40, 45, 60, and 90 deg, epoxy coating has the least effect on the bond strength of steel reinforcing bars to concrete when the rib face angle is greater than or equal to 45 deg.

Keywords: bond (concrete to reinforcement); deformed reinforcement; epoxy resins; friction; reinforcing steels; splicing; structural engineering.

INTRODUCTION

The negative impact of epoxy coating on the bond strength between reinforcing steel and concrete is well established (Treece and Jirsa, 1989; Choi et al., 1991; Hester et al., 1993; Hadje-Ghaffari et al., 1994). The lower relative bond strength of coated reinforcement is generally attributed to a lower coefficient of friction for epoxy-coated surfaces than provided by uncoated surfaces. This point is usually stated without a specific understanding of the differences in coefficient of friction between coated and uncoated surfaces or of the role played by the rib face angle (angle between the longitudinal direction and the forward face of a reinforcing bar deformation) on bond behavior. Assumptions as to the value of the coefficient of friction of epoxy-coated bars have included estimates as low as zero.

As data has accumulated on the differences in bond behavior of epoxy-coated and uncoated bars, it has been universally observed that concrete exhibits good adhesion to uncoated bars and virtually no adhesion to epoxy-coated bars. Following failure, epoxy-coated bars are usually clean, with no concrete residue left on the bars, while concrete in contact with epoxy-coated bars has a smooth, glassy surface. Occasionally, the epoxy coating is crushed against the concrete, but in general, the epoxy is undamaged. In contrast, uncoated bars exhibit particles of cement paste and mortar adhering to the shaft and sides of the deformations following failure.

It is often reasoned that an increase in face angle will decrease the negative impact of epoxy coating on bond strength, although earlier research has demonstrated that there is a limit to the role of the face angle on the bond strength of uncoated bars (Rehm, 1961; Lutz and Gergely, 1967). Lutz and Gergely (1967) showed that the slip of an uncoated reinforcing bar with a high face angle has the effect of crushing the concrete in front of the ribs, producing a rib with an effective angle between 30 and 40 deg, which rather than the steel itself acts as a wedge. Skorobogatov and Edwards (1979) further demonstrated that a change in face angle from 48.5 to 57.8 deg does not affect bond strength. Like Lutz and Gergely, they concluded that high rib face angles are flattened by crushed concrete, which reduces the effective face angle to a smaller value.

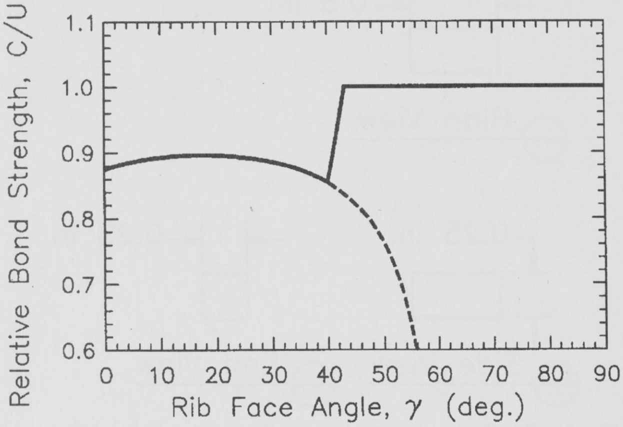

Fig. 1—Theoretical relationship between relative bond strength of epoxy-coated bars to uncoated bars (C/U) versus rib face angle γ.

The effect of the face angle on the relative bond strength of coated to uncoated reinforcement C/U has been under study for a number of years. Choi, Darwin, and McCabe (1990) derived a theoretical statical relationship between C/U and the rib face angle γ based on a constant maximum confining force provided by the concrete

$$C/U = \frac{(\tan\gamma + \mu_c)(1-\mu_u \tan\gamma)}{(\tan\gamma + \mu_u)(1-\mu_c \tan\gamma)} \tag{1}$$

in which μ_c and μ_u are the coefficients of friction (COF) for epoxy-coated and uncoated bars, respectively. In the derivation, Choi et al. assumed that the cohesion between a steel reinforcing bar and concrete drops to zero once any relative movement occurs and that differences in bond strength depend only on the coefficients of friction. This relationship, illustrated by the curved line (solid and dashed) in Fig. 1, first increases and then decreases with increasing face angle. In follow-up work, Hadje-Ghaffari, Darwin, and McCabe (1991) limited the maximum value of γ for uncoated bars to values between 30 and 40 deg, based on the observations of Lutz and Gergely (1967). If an upper limit is placed on the value of γ for uncoated bars, C/U increases rapidly to a value of 1.0 for values of γ greater than γ_{max}, as shown in Fig. 1 for γ_{max} = 40 deg. In the case illustrated, C/U = 1.0 for $\gamma \geq 43$ deg.

With this background, the goals of the current study are to establish realistic values for the coefficients of friction between concrete and epoxy-coated and uncoated reinforcing steel and to determine the effect of rib face angle on the relative strength

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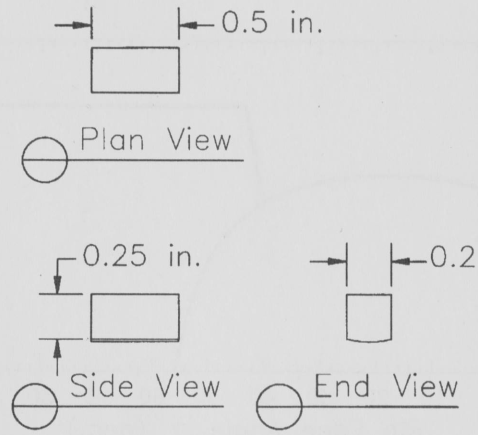

Fig. 2—Reinforcing steel specimen for friction test (1 in. = 25.4 mm).

of epoxy-coated reinforcement. Full details of the study are presented by Idun and Darwin (1995).

RESEARCH SIGNIFICANCE

Epoxy-coated reinforcement plays a key role in improving the durability of reinforced concrete structures subjected to chlorides. However, the resulting reduction in bond strength requires increased development and splice lengths for epoxy-coated steel, which, in turn, increase both the congestion of the reinforcement and the cost of these structures. An improved understanding of the roles played by the interfacial properties of steel and concrete and by the geometry of the reinforcing bars on bond is needed to develop realistic strategies for improving the bond strength of epoxy-coated reinforcement. Studies by Choi et al. (1991) and Darwin et al. (1996a) have demonstrated that the relative bond strength of epoxy-coated bars can be increased by increasing the relative rib area R_r* of the bars. This study pursues another approach to achieving the same end.

One earlier study used steel plate to establish the coefficient of friction between epoxy-coated and uncoated steel plates and concrete (Cairns and Abdullah, 1994). The current study represents the first to establish the coefficient using reinforcing bars.

EXPERIMENTAL WORK

The experimental work encompassed two areas. The first established the coefficients of friction between epoxy-coated and uncoated reinforcement and mortar, and the second established the effect of face angle on the relative bond strength C/U of coated reinforcement.

Coefficients of friction

The coefficients of friction between epoxy-coated and uncoated reinforcing steel and mortar were measured using 130 test specimens mounted in a friction test fixture.

*Relative rib area R_r is ratio of projected rib area to product of nominal bar perimeter and center-to-center rib spacing.

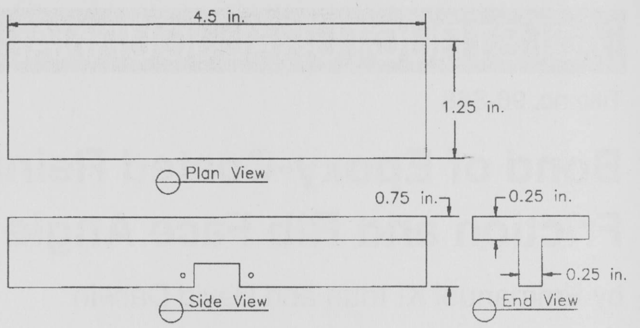

Fig. 3—Steel yoke for mounting reinforcing steel specimen (1 in. = 25.4 mm).

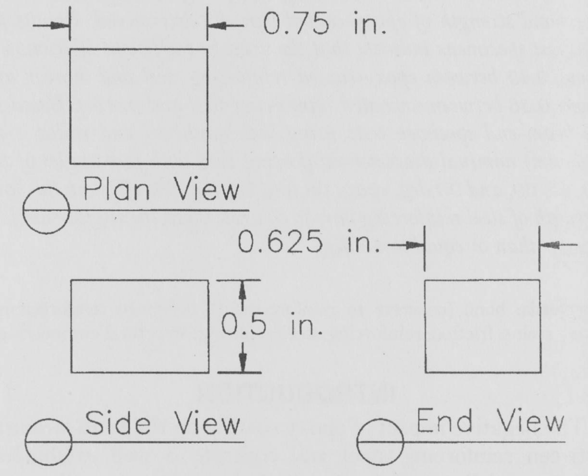

Fig. 4—Mortar specimen for friction test (1 in. = 25.4 mm).

Test specimens—The test specimens consisted of pieces of reinforcing steel in contact with small mortar blocks. The steel specimens (Fig. 2), measuring 1/4 in. (6.35 mm) thick, 1/2 in. (12.7 mm) long, and 1/4 in. (6.35 mm) wide, were cut from two No. 11 (No. 36) steel reinforcing bars, one epoxy-coated and one uncoated, from between the ribs on the bars. The barrel of each bar provided the testing surface. For the tests, the steel was placed in the slot of a reusable yoke (Fig. 3). The mortar specimens (Fig. 4) measured 1/2 x 5/8 x 3/4 in. (12.7 x 15.9 x 19.1 mm).

Materials—Epoxy-coated and uncoated conventional ASTM A 615 Grade 60 No. 11 (No. 36) deformed reinforcing bars with a bamboo pattern (ribs perpendicular to the axis of the bar) were used. The bamboo pattern was used because it offered enough room between the ribs to cut the specimens. The fusion-bonded epoxy coating was commercially applied in accordance with ASTM A 775 and had a thickness of 10 mils (250 μm). The mortar was made using Type I portland cement and Kansas River sand (specific gravity ssd = 2.62, absorption = 0.5 percent) that had been passed through a No. 16 sieve. A water-cement ratio of 0.5 and a sand-cement ratio of 1.5 were used to produce mortar with strengths of 5610 to 6860 psi (38.7 to 47.3 MPa) at 7 days.

Test procedures—The test fixture, shown in Fig. 5, is mounted on a 110-kip (490-kN) capacity closed-loop, servo-hydraulic testing machine. Prior to the test, the mortar specimen is placed on the base of the specimen guide against a steel stopper with a formed surface facing upward. The steel stopper, which is about 1/8-in. (3-mm) lower than the mortar specimen, prevents the mortar from moving during the test when the yoke is pulled by the jack. The steel specimen is mounted in the slot in the steel yoke (Fig. 3 and 5) with the original surface of the reinforcing bar exposed. The front edge of the steel specimen is positioned to project over the front edge of the mortar so as not to dig into the mortar during the test. The yoke is connected to a load cell, which connects to a 3/4 in. (19 mm) threaded rod

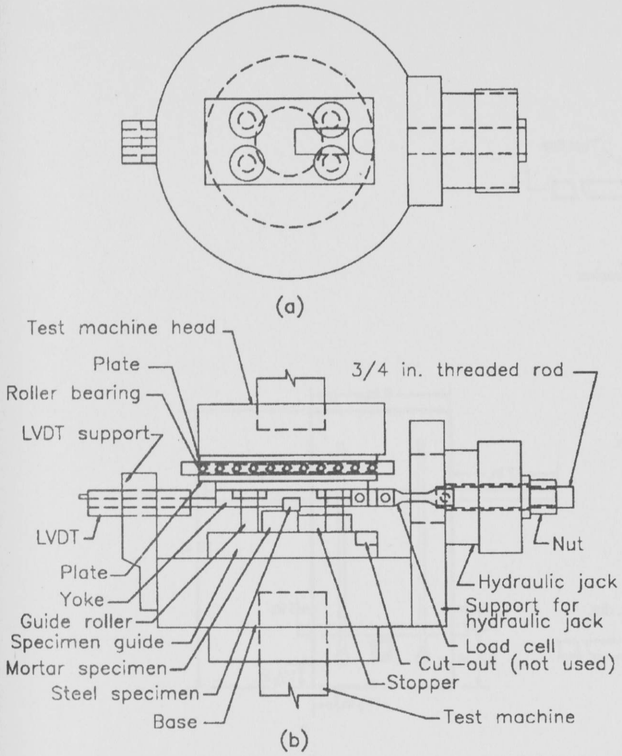

Fig. 5—Friction test apparatus: (a) plan view of hydraulic jack, support for hydraulic jack, specimen guide, stopper, and LVDT support for friction test apparatus; and (b) side view of assembled friction test apparatus (1 in. = 25.4 mm).

running through a 5 ton hollow-core hydraulic jack. Two steel plates, separated by roller bearings, are placed on top of the yoke. This allows the yoke to move when pulled by the hydraulic jack, while the vertical load is applied to the top plate. The vertical load is applied by means of the closed-loop testing machine and is kept constant throughout the test. In this study, vertical loads ranged from 51 to 272 lb (227 to 1210 N). The horizontal load was applied by the hollow-core jack at a rate of about 10 lb (45 N) per sec.

Horizontal displacement (slip) between the steel and mortar was monitored using a spring loaded linear variable differential transformer (LVDT) mounted at the nonloaded end of the yoke. Tests lasted 1 to 2 min; steel specimens were used only once. 1-in. (25-mm) square by 3-in. (76-mm) mortar prisms were tested to determine compressive strength.

Effect of face angle on C/U

To determine the effect of face angle on the relative bond strength of epoxy-coated reinforcement, 58 beam-end specimens were tested using both conventional and specially machined reinforcing bars with face angles of 30, 40, 45, 60, and 90 deg.

Test specimens—ASTM A 944 beam-end specimens, originally developed by Darwin and Graham (1993a, 1993b), were used in this study (Fig. 6). Each specimen contained a 1 in. (25 mm) nominal diameter bottom-cast test bar with a 2 in. (51 mm) cover and 15 in. (381 mm) of concrete above the bar, for a total depth of 18 in. (457 mm). The specimens were 9 in. wide x 24 in. (229 x 610 mm) long.

Test bars extended 22 in. (560 mm) out from the face of the specimens. Bonded lengths (lengths of test bars in contact with the concrete) and lead lengths (lengths of test bars at the loaded end not in contact with the concrete) for the beam-end specimens were set at 12 in. (305 mm) and 0.5 in. (12.7 mm), respectively. Two polyvinyl chloride (PVC) pipes, with an inside

Table 1(a)—Properties and designations of machined bars*

Bar designation	Normal diameter, in.	Rib face angle, deg	Rib radius, in.	Rib spacing, in.	Average rib height, in.	Relative rib area	Average coating thickness,† mils
M1	1.00	90.00	0.030	0.550	0.100	0.200	9.9
M45.3	1.00	45.00	0.030	0.550	0.075	0.150	8.5
M45.4	1.00	45.00	0.040	0.550	0.075	0.150	8.5
M60.3	1.00	60.00	0.030	0.550	0.075	0.150	8.5
M60.4	1.00	60.00	0.040	0.550	0.075	0.150	8.5

*Machined bars fabricated from 110 ksi yield strength ASTM A 311 cold-rolled steel.
†Average coating thicknesses for coated bars belonging to bar designation.
Note: 1 ksi = 6.89 MPa; 1 in. = 25.4 mm; 1 lb/ft = 1.49 kg/m; 1 mil = 0.001 in. = 25.4 μm.

Table 1(b)—Properties and designations of rolled reinforcing bars*

Bar designation	Nominal diameter, in.	Rib face angle, deg.	Weight per ft, lb	Rib spacing, in.	Rib height ASTM	Rib height average†	Relative rib area	Average coating thickness,‡ mils
C1	1.00	40	2.529	0.504	0.064	0.060	0.101	13.3
F1	1.00	40	2.600	0.471	0.078	0.074	0.140	16.8
F2	1.00	30	2.551	1.006	0.086	0.080	0.072	16.8

*Rolled bar yield strengths = 60, 75, and 75 ksi for C1, F1, and F2 bars, respectively.
†Average rib height between longitudinal ribs.
‡Average coating thicknesses for coated bars belonging to bar designation.
Note: 1 ksi = 6.89 MPa; 1 in. = 25.4 mm; 1 lb/ft = 1.49 kg/m; 1 mil = 0.001 in. = 25.4 μm.

diameter matching that of the bar, located at the loaded end and 12.5 in. (318 mm) from the loaded end, were used to control the lead and bonded lengths of the test bar, respectively. A 1 in. (25 mm) diameter steel conduit, adjacent to the unloaded end of the test bar and extending to the end of the specimen, provided access for measuring unloaded end slip using a spring-loaded LVDT.

Materials—Two types of reinforcing steel were used: machined bars fabricated from 110 ksi (758 MPa) yield strength ASTM A 311 cold-rolled steel and No. 8 [No. 25] mill-rolled deformed bars satisfying ASTM A 615. Five bamboo deformed patterns (M1, M45.3, M45.4, M60.3, and M60.4) were used for the machined bars (Fig. 7). The bars had a 0.55 in. (14 mm) rib spacing and a 1.0 in. (25 mm) nominal diameter. The M1 bars had ribs with a face angle of 90 deg and a height of 0.1 in. (2.5 mm), providing a relative rib area R_r of 0.2 and a rib radius (the radius of curvature between the rib face and the rib top surface and the bottom fillet) of 0.02 in. (0.51 mm). The other bars had ribs with a face angle of 45 or 60 deg, and a height of 0.075 in. (1.9 mm), providing R_r of 0.15, and rib radii of 0.03 or 0.04 in. (0.76 or 1.01 mm).

The three ASTM A 615 No. 8 [No. 25] bars used in this study, designated C1, F1, and F2, had face angles (measured at the midheight of the ribs) of 40, 40, and 30 deg, respectively, and R_r values of 0.101, 0.140, and 0.072 (Fig. 8). The properties of the machined and rolled bars are summarized in Table 1(a) and l(b), respectively. Epoxy coating was commercially applied to both the machined and conventional reinforcement. The beam-end specimens were fabricated using air entrained concrete supplied by a local ready-mix plant. The concrete contained Type I portland cement, Kansas River sand, and 3/4 in. (19 mm) maximum nominal size crushed limestone. Concrete strengths, f'_c ranged from 4340 to 5440 psi (29.9 to 37.5 MPa) at test stages of 7 to 18 days.

Test procedures—The specimens were tested in accordance with ASTM A 944. Load was applied at a rate of approximately 6 kips (27 kN) per min. The tensile force on the bar was counteracted by a compressive force imposed on the concrete

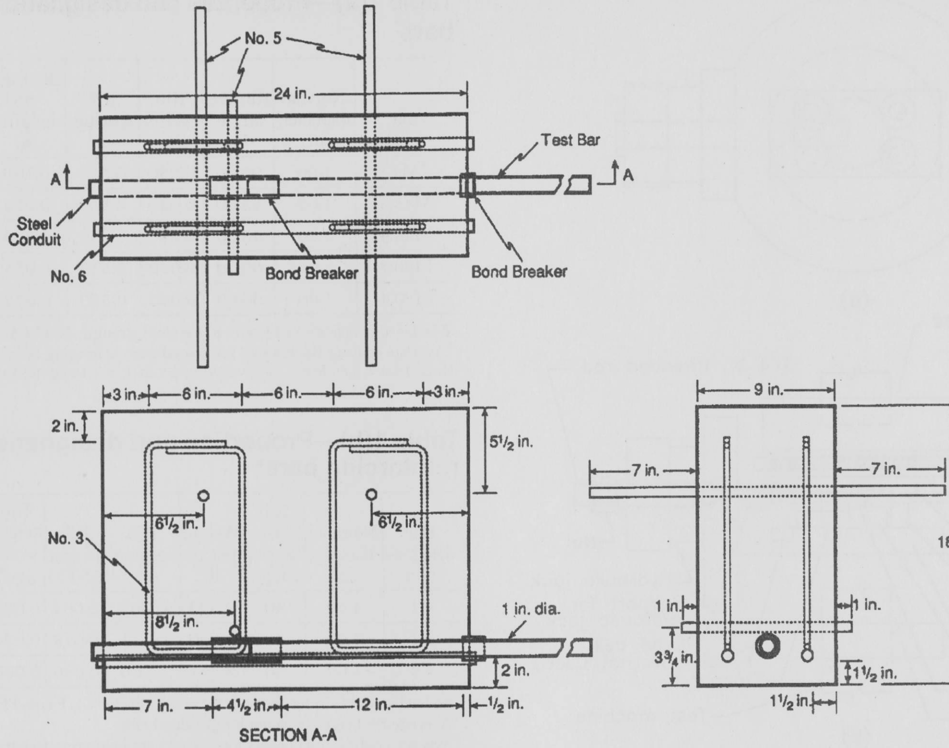

Fig. 6—Beam-end test specimen (ASTM A 944) (1 in. = 25.4 mm).

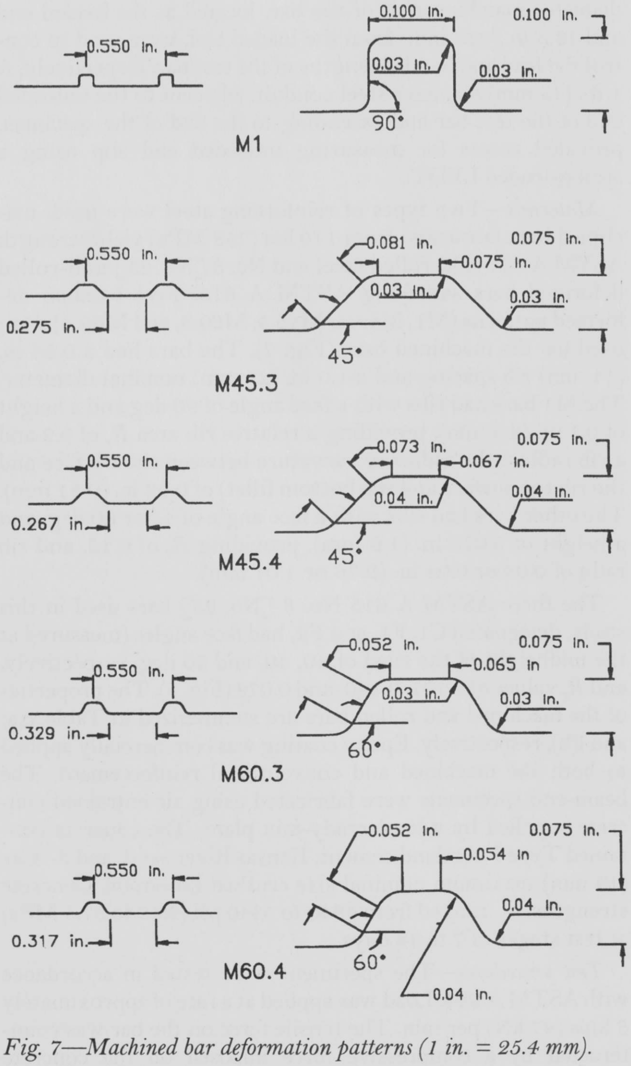

Fig. 7—Machined bar deformation patterns (1 in. = 25.4 mm).

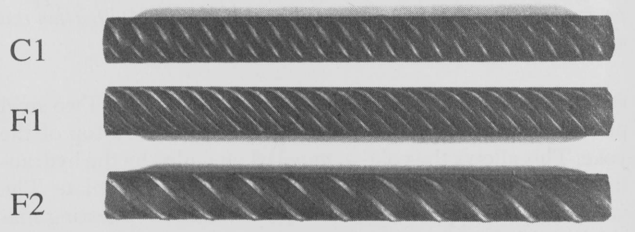

Fig. 8—ASTM A 615 No. 8 rolled bar deformation patterns.

through a bearing pad by the frame of the testing assembly. The center of the pad was located 13.75 in. (350 mm) from the center of the test bars. Tests lasted about 10 min. Standard 6 x 12 in. (150 x 300 mm) concrete cylinders were tested in compression soon after completing the beam-end tests.

TEST RESULTS AND EVALUATION

Coefficients of friction

Apart from a few mortar specimens that crushed due to excessive vertical loads (the results of these specimens were discarded), as the vertical load was maintained and the horizontal load applied and increased steadily, the steel specimen slipped relative to the mortar. This continued until a peak horizontal load was attained, after which the horizontal load dropped steadily with increasing slip (the drop was more rapid for coated steel), with the steel specimens leaving indentations in the surface of the mortar. These indentations were generally more pronounced as the applied vertical load increased. Some mortar powder was also produced, with the amount increasing with the vertical load.

The coefficient of friction (COF) is evaluated in two ways. The first is based on the evaluation of the individual COF, which is obtained by dividing the maximum shear force (peak horizontal load) by the normal force (constant vertical load) for each test, from which mean values are calculated. The second is based on linear regression analysis (best fit lines) of maximum shear force versus normal force to obtain a single COF.

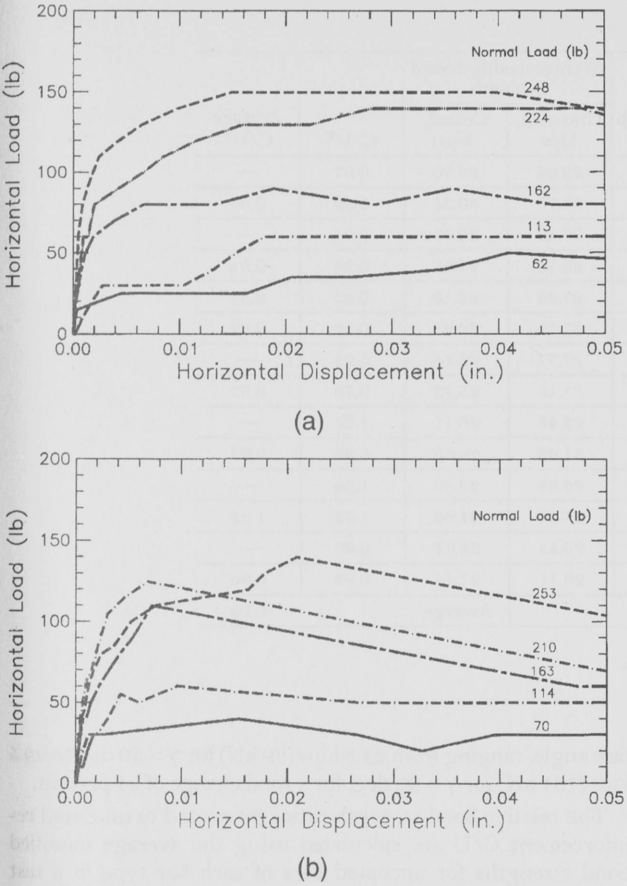

Fig. 9—Typical horizontal load versus horizontal displacement curves for: (a) uncoated reinforcing bar specimens in friction test apparatus; and (b) coated reinforcing bar specimens in friction test apparatus (1 lb = 4.45 N; 1 in. = 25.4 mm).

Typical horizontal load versus slip curves are presented in Fig. 9(a) and 9(b), for uncoated and epoxy-coated specimens, respectively. The curves differ in that the horizontal loads for the uncoated specimens remain nearly constant after reaching a peak value, while the horizontal loads for the epoxy-coated specimens decrease steadily after the peak load is attained. A summary of the test results is presented in Table 2.* The results indicate that the mean COF varies from 0.503 to 0.627 for uncoated specimens and from 0.379 to 0.591 for epoxy-coated specimens, with a weighted mean COF of 0.561 for uncoated specimens and 0.491 for epoxy-coated specimens. With the exception of the results in Group T1, the mean COF is lower for epoxy-coated specimens than for uncoated specimens.

Fig. 10(a) and 10(b) are the best-fit plots of maximum shear force versus normal force for the uncoated and coated specimens, respectively. From these plots, the intercepts, slopes (COF), and the coefficients of determination r^2 are, respectively, –0.43 lb (–1.9 N), 0.565, and 0.89 for uncoated specimens and 2.4 lb (10.7 N), 0.480 and 0.86 for epoxy-coated specimens. The ratio of the coefficients of friction for epoxy-coated to uncoated specimens is 0.85, indicating a 15 percent reduction due to epoxy coating.

For the narrow range of mortar strengths evaluated, a comparison based on the mean values of COF indicates no clear relationship between COF and mortar strength (Table 2).

*Individual test results presented by Idun and Darwin (1995) and in Appendix A.†

†The Appendix is available in xerographic or similar form from ACI headquarters, where it will be kept permanently on file, at a charge equal to the cost of reproduction plus handling at time of request.

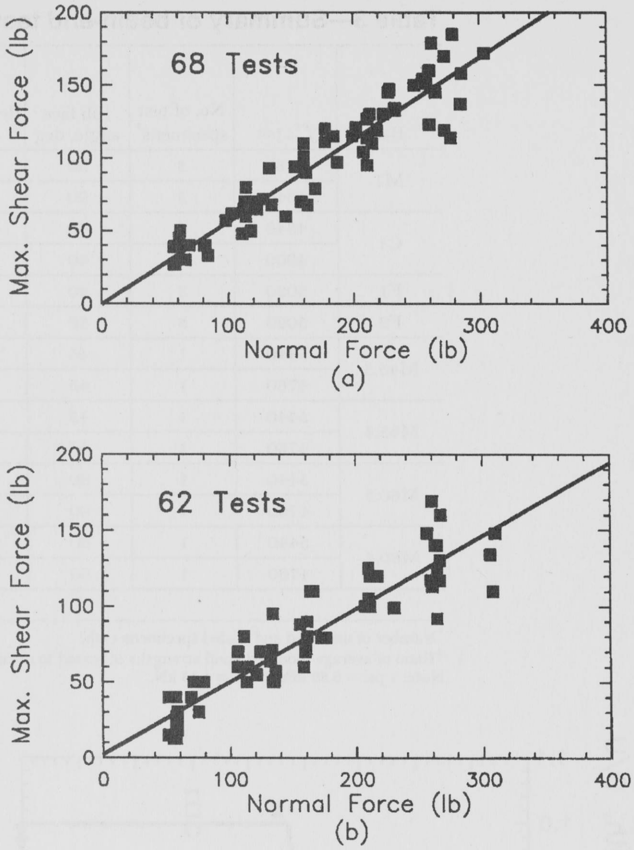

Fig. 10—Maximum shear force versus normal force for reinforcing bar specimens: (a) uncoated; and (b) epoxy-coated (1 lb = 4.45 N).

Table 2—Summary of friction test results

Test group no.	Mortar strength, psi	Uncoated		Coated*	
		No. of tests	Mean COF	No. of tests	Mean COF
T1	6420	10	0.573	10	0.591
T2	5770	10	0.627	9	0.463
T3	5610	10	0.546	9	0.429
T4	5670	10	0.503	9	0.379
T5	6860	10	0.528	6	0.483
T6	6250	8	0.533	10	0.521
T7	6420	10	0.608	9	0.555
	Weighted mean		0.561		0.491
	Standard deviation		0.088		0.123
	COV, percent		15.8		25.1

*Coating thickness = 10 mils = 0.010 in. = 250 μm.
Note: 1 psi = 6.89 kPa.

The mean values of COF at the steel-mortar interface of 0.56 for an uncoated surface and 0.49 for an epoxy-coated steel surface (Table 2) compare with average COF values of 0.527 for a millscale steel surface and 0.487 for an epoxy-coated steel surface, obtained for steel plates by Cairns and Abdullah (1994). The coefficient of friction for the epoxy-coated steel obtained in this study is nearly identical to that obtained by Cairns and Abdullah, while the COF for uncoated steel is higher than that obtained in the earlier study. The difference is likely due to the different steel surfaces used. Considering the scatter in the data (standard deviation = 0.088), however, the results are quite close.

Table 3—Summary of beam-end tests

Bar	f'_c, psi	No. of test specimens*	Rib face angle, deg	Relative rib area	Average modified bond strength: Uncoated, kips	Average modified bond strength: Coated, kips	C/U†	Average C/U†
M1	5180	3	90	0.200	29.68	28.70	0.97	—
	4340	3	90	0.200	30.70	30.31	0.99	0.98
C1	4340	6	40	0.101	27.82	26.07	0.94	—
	4900	3	40	0.101	29.13	27.25	0.94	0.94
F1	5020	3	40	0.140	27.26	23.16	0.85	0.85
F2	5020	3	30	0.072	27.12	22.27	0.82	0.82
M45.3	5440	1	45	0.150	27.77	25.34	0.91	—
	4760	1	45	0.150	31.15	23.13	0.74	0.83
M45.4	5440	1	45	0.150	25.48	26.11	1.02	—
	4760	1	45	0.150	31.03	29.06	0.94	0.98
M60.3	5440	1	60	0.150	25.84	26.80	1.04	—
	4760	1	60	0.150	31.04	31.66	1.02	1.03
M60.4	5440	1	60	0.150	25.85	25.71	0.99	—
	4760	1	60	0.150	29.11	27.15	0.93	0.96
						Average		0.92

*Number of uncoated and coated specimens each.
†Ratio of average modified bond strengths of coated to uncoated bars.
Note: 1 psi = 6.89 kPa; 1 kip = 4.45 kN.

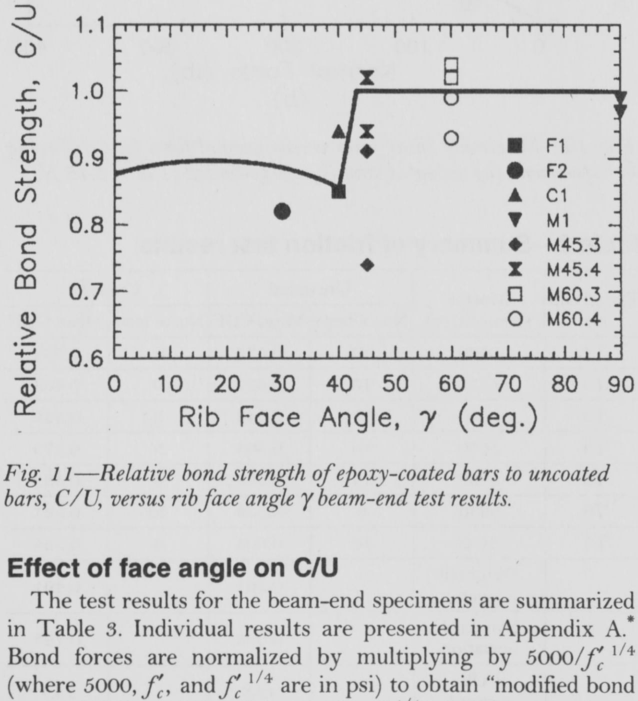

Fig. 11—Relative bond strength of epoxy-coated bars to uncoated bars, C/U, versus rib face angle γ beam-end test results.

Effect of face angle on C/U

The test results for the beam-end specimens are summarized in Table 3. Individual results are presented in Appendix A.* Bond forces are normalized by multiplying by $5000/f'_c{}^{1/4}$ (where 5000, f'_c, and $f'_c{}^{1/4}$ are in psi) to obtain "modified bond strengths" [use of the 1/4 power for $f'_c{}^{1/4}$ is based on the observations of Darwin et al. (1995b, 1996b)].

The results support earlier observations on the general insensitivity of the bond strength of uncoated bars to rib face angle (Lutz and Gergely, 1967; Skorobogatov and Edwards, 1979). The weighted average modified bond forces for uncoated Bars F2, C1, F1, M45.3, M45.4, M60.3, M60.4, and M1 with face angles of 30, 40, 40, 45, 45, 60, 60, and 90 deg, respectively are 27.1, 28.3, 27.3, 29.5, 28.3, 28.4, 27.5, and 30.2 kips (121, 126, 121, 131, 126, 126, 122, and 134 kN). The total range in the data is just 10 percent, based on the highest value. In contrast, the bond strengths of the coated bars show much greater sensitivity to face angle, ranging from 22.3 kips (99 kN) for γ = 30 deg to 29.5 kips (131 kN) for γ = 90 deg, for a total change of 24 percent.

The relative bond strength ratios for coated to uncoated reinforcement C/U are calculated using the average modified bond strengths for uncoated bars of each bar type in a test group. The average calculated C/U ratio for each bar type is presented in Table 3. As shown in the table, the C/U ratios range from 0.74 to 1.04, with an average value of 0.92.

The effect of rib face angle γ on the C/U ratio is compared with the theoretical relationship (first illustrated in Fig. 1) in Fig. 11. The earlier observation that C/U ratio should equal 1.0 for γ ≥ 43 deg is supported by the test results for the M45.4 bars (γ = 45 deg) with an average C/U ratio of 0.98, the M60.3 and M60.4 bars (γ = 60 deg) with average C/U ratios of 1.03 and 0.96, respectively, and the M1 bars (γ = 90 deg) with an average C/U ratio of 0.98. The only deviation is provided by the two M45.3 tests, with individual C/U ratios of 0.91 and 0.74, of which only the last data point represents a significant deviation. Overall, a value of γ greater than or equal to 45 deg appears to provide for the minimum effect of epoxy coating on the bond strength of reinforcing steel.

It is worth noting that the C/U ratio obtained in the current tests are generally higher than those obtained in previous studies (Choi et al., 1990; 1991). From Table 3 and Fig. 11, it is noted that the F2 bars, the bars with the lowest relative rib area (R_r = 0.073) also have the lowest C/U ratio. The values of R_r for the other bars used in the study are higher than those used in earlier tests. The higher relative strength of epoxy-coated bars with high values of R_r is supported by full-scale splice tests (Darwin et al., 1995a; 1996a). It is also worth noting that it is difficult to roll (and, for that matter, coat) bars with face angles steeper than 45 deg. In practice, most reinforcing bars have face angles between 30 and 45 deg, a region in which high variability in the effect of epoxy coating on bond strength is expected, as shown in Fig. 11.

CONCLUSIONS

The following observations and conclusions are based on the results and analyses of the experimental work presented in this report.

*The Appendix is available in xerographic or similar form from ACI headquarters, where it will be kept permanently on file, at a charge equal to the cost of reproduction plus handling at time of request.

1. Epoxy coating reduces the coefficient of friction between reinforcing steel and mortar. The average coefficient of friction at the steel-mortar interface is about 0.56 for an uncoated steel surface and about 0.49 for an epoxy-coated steel surface.

2. For the limited range of mortar strengths tested, the coefficient of friction between steel and mortar appears to have no relationship to mortar strength.

3. The theoretical relationship, illustrated in Fig. 1 and 11, relating the relative bond strengths of coated to uncoated bars C/U to rib face angle, is supported by the results of the beam-end specimen tests.

4. Based on the beam-end tests, epoxy coating has the least effect on bond strength for bars with rib face angles greater than or equal to 45 deg.

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