

# BEAM-END BOND TESTS OF TEXTURED-EPOXY-COATED NO. 6 REINFORCING BARS

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A Report on Research Sponsored by the  
CRSI EDUCATION AND RESEARCH FOUNDATION

Structural Engineering and Engineering Materials  
SL Report 24-1  
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THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.  
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## ABSTRACT

In this study, the bond strength of No. 6 textured-epoxy-coated reinforcement (TECR)–epoxy-coated reinforcement with a texturing surface treatment material–is evaluated. The bond strength of the TECR, produced by Sherwin-Williams, is compared to that of uncoated reinforcement using beam-end tests performed in accordance with ASTM A944 and A1124 using six pairs of TECR and uncoated bar specimens. The TECR exhibited a bond strength equal to 100.3 percent of that of uncoated reinforcement from the same heat of steel. The difference in bond strength is not statistically significant. The test results can be used to develop bond qualification recommendations for reinforcing bars with textured coating to be incorporated in ASTM A1124. Based on these results, it is recommended that the required bond strength of TECR be increased from 96% to 99.5% of the bond strength of uncoated bars and that the textured coating be considered as providing bond strength equivalent to that of uncoated bars.

**Keywords:** beam-end test, bond strength, epoxy-coated reinforcement, textured-epoxy-coated reinforcement, uncoated reinforcement

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# CHAPTER 1: INTRODUCTION

The ACI Building Code and AASHTO Bridge Specifications require that the development and splice lengths of straight epoxy-coated reinforcement (ECR) be 20 to 50 percent longer than that for uncoated reinforcement. Recently completed research at the University of Kansas (KU) (Aryal et al. 2023) has shown that straight textured-epoxy-coated reinforcement (TECR) has the same splice strength as uncoated bars, offering the potential of using the same development and splice lengths for the two types of reinforcement.

The TECR evaluated in this study is produced by Sherwin-Williams. The coating consists of a conventional epoxy coating satisfying the requirements of ASTM A775 overlaid by a texturing surface treatment material. The combined coating provides corrosion protection along with both improved bond strength and damage tolerance.

To establish the full advantages of TECR, tests are required to demonstrate that textured epoxy-coated bars have bond strengths equal to the bond strengths of uncoated bars. Doing so will permit the use of a coating factor of 1.0 (the same as used for uncoated bars) for developing TECR bars. In addition, beam-end tests are needed with uncoated and TECR bars with a relative rib area between 0.075 and 0.085 to meet the requirements of the new ASTM specification for TECR (ASTM A1124).

This report describes beam-end bond tests performed in accordance with ASTM A944 on TECR. The beam-end tests were performed on TECR and uncoated reinforcement manufactured from the same heat of ASTM A615 reinforcement.

## 1.1 Background

Studies of epoxy-coated reinforcement have shown that the decrease in bond strength of the bars is due to the reduction in the coefficient of friction of the coated surface with the concrete

(Treece and Jirsa 1989, Choi et al. 1991). Prior to recent splice tests at KU, using beam-end tests, Ross et al. (2021) reported, based on slip—not bond strength—that the textured epoxy-coated bars exhibited improved bond strength when compared to conventional epoxy-coated bars. Tests by Aryal et al. (2023) performed at the University of Kansas included 36 beam-end specimens and 26 lap splice specimens. The test parameters included bar size (No. 6 or No. 11), nominal concrete compressive strength (5 or 10 ksi), splice length (ranging from 16 to 69 in.), and coating type (uncoated, epoxy-coated, TECR). In the beam-end tests, the mean bond strengths of the TECR was 97 to 100% of that of uncoated reinforcement. The mean bond strength of the TECR lap splice specimens was 105% that of uncoated reinforcement. These results served as the basis for the new ASTM specification (ASTM A1124), which requires a relative bond strength of 96% compared with uncoated bars. Because of the 96% requirement, the specification was written to describe texturing surface treatment material as “a product applied immediately following the application of a fusion-bonded epoxy coating to improve bond strength to concrete,” rather than as a product that “provides a reinforcing bar with bond strength to concrete equal to that obtained for an uncoated bar,” as it appeared in the initial draft of the specification.

A key objective of this study is to provide technical support to modify the specification to return to the original definition of a texturing surface treatment material. The No. 6 bars used in the study by Aryal et al. (2023) had a relative rib area of 0.092, which is outside the range 0.075 to 0.085, as required by the new specification (ASTM A1124) and would not have satisfied the specification, even if a higher relative strength had been attained. In this study, six uncoated bar/TECR reinforcement beam-end specimen pairs using reinforcement with a relative rib area within the limits specified by ASTM A 1124 were tested to establish if the TECR produced using

the Sherwin-Williams textured coating material provides bond strength sufficient to increase the relative bond strength requirements in ASTM A1124.

## CHAPTER 2: EXPERIMENTAL WORK

### 2.1 Materials

#### 2.1.1 Bar Properties

The properties of the reinforcing bars used in beam-end test specimens are reported in Table 2.1. The coating thickness measurements are shown in Table 2.2.

**Table 2.1:** Properties of Reinforcement

Bar Size	Nominal Diameter (in.)	Yield Strength <sup>†</sup> (ksi)	Tensile Strength <sup>†</sup> (ksi)	Avg. Def. Spacing (in.)	Avg. Def. Height* (in.)	Avg. Def. Height Side 1** (in.)	Avg. Def. Height Side 2** (in.)	Gap Width Side 1 (in.)	Gap Width Side 2 (in.)	Relative Rib Area, R <sub>r</sub> **
No. 6	0.75	68	104	0.507	0.048	0.047	0.046	0.175	0.175	0.078

<sup>†</sup> Per ASTM A370

\*Per ASTM A615

\*\*Per ACI 408R-03

\* 1 in. = 25.4 mm; 1 ksi = 6.89 MPa

**Table 2.2:** Coating Thickness (mils)

Location on bar	Side 1				Side 2			
	A	B	C	Average	A	B	C	Average
1	9.0	12.0	10.0	10.3	22.0	20.0	16.0	19.3
2	16.0	14.0	14.2	14.7	16.0	22.0	21.0	19.7
3	12.0	15.0	13.0	13.3	23.0	19.0	21.5	21.2
4	16.0	16.0	18.0	16.7	17.0	18.0	20.0	18.3
5	9.5	15.0	14.0	12.8	15.0	12.0	15.0	14.0
<b>Overall Average (mils) =</b>								<b>16.04</b>

**Table 2.3:** R<sub>z</sub> Readings for Three Bars (mils)

Reading	Bar 1	Bar 2	Bar 3
1	8.47	10.22	9.75
2	9.58	11.04	10.98
3	8.96	10.47	9.69
4	9.21	9.94	9.89
5	9.86	11.49	10.24
<b>Average</b>	<b>9.21</b>	<b>10.63</b>	<b>10.11</b>

The test bars meet the requirements of ASTM A615, and in accordance with ASTM A1124, they have a relative rib area within the range 0.075 to 0.085, an average coating thickness between 10 and 20 mils with no single recorded coating thickness measurement less than 80 % of the specified minimum thickness or more than 120 % of the specified maximum thickness, and an average value of  $R_z$  between 8 and 18 mils.

### 2.1.2 Concrete

The concrete used to fabricate the test specimens was supplied by a local ready-mix plant. The concrete contained Type 1L portland cement, Kansas River sand, 3/4-in. nominal maximum size crushed limestone, and had a water-cement ratio of 0.438. Adva 140M, a superplasticizer, was used to improve the workability of the mix. The mixture proportions of the concrete are provided in Table 2.4.

**Table 2.4:** Concrete Mixture Proportions Based on Saturated Surface-Dry Aggregate

<b>Material</b>	<b>Quantity (SSD)</b>
Type 1L Cement	600 lb/yd <sup>3</sup>
Water	263 lb/yd <sup>3</sup>
Kansas River Sand	1396 lb/yd <sup>3</sup>
Crushed Limestone	1735 lb/yd <sup>3</sup>
Superplasticizer Adva 140M	40 fl oz
Set Retarder	12 fl oz

Bulk specific gravity (SSD) of Kansas River sand is 2.63, and that of crushed limestone is 2.595.

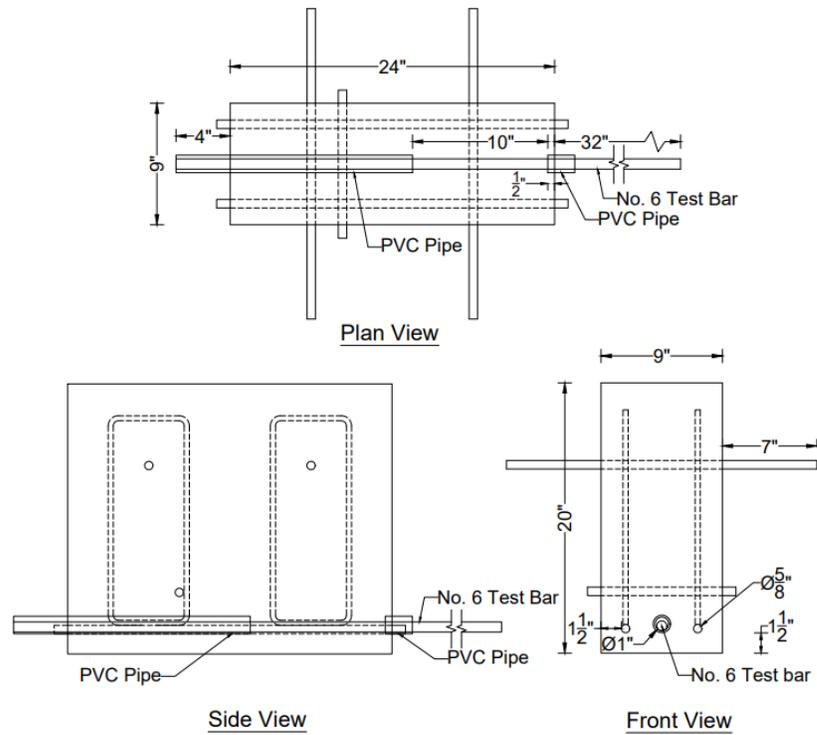
## 2.2 Specimen Preparation and Testing

The specimens were prepared and tested in accordance with ASTM A944 and had dimensions (width × length × depth) of 9 × 24 × 20 in. Specimens containing uncoated bars and specimens containing TECR were alternated in the order of casting to minimize the effects of differences in concrete properties from different portions of the batch, as recommended in ASTM

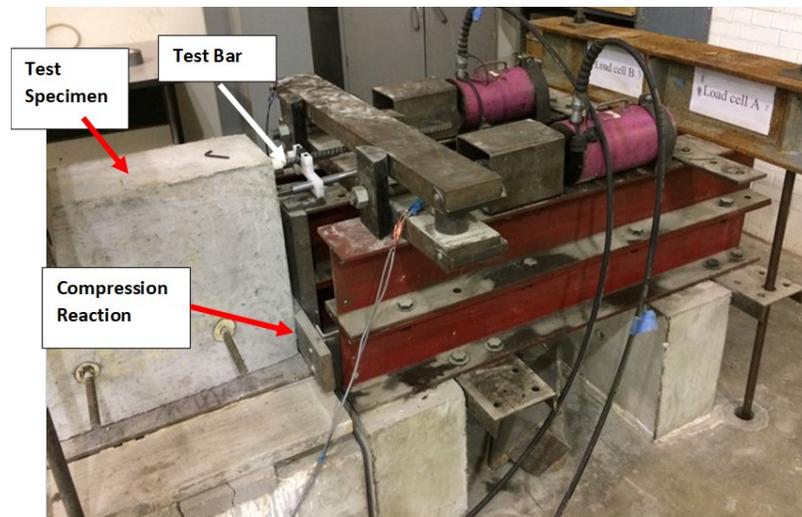
A944. Test cylinders were cast in accordance with ASTM C192 and cured under the same ambient conditions as the test specimens.

The beam-end test specimen is shown in Figure 2.1. The specimens contain a single bottom-cast No. 6 test bar in a concrete prism with additional ancillary reinforcement outside of the test region to prevent flexural or shear failure of the specimen. The specimens are inverted prior to testing, and the test bar is loaded hydraulically with the compression reaction from the test frame placed far from the test bar to minimize confinement (Figure 2.2). A nominal bonded length of 10 in. is used to ensure that the specimen fails in bond prior to yielding of the bar, and a lead length of 0.5 in. is used to prevent conical failure.

Twelve beam-end specimens, six with uncoated bars and six with TEQR, were cast and tested at an age of six or seven days when the concrete strength was between 4500 and 5500 psi. During the tests, displacements at the loaded and unloaded ends of the bars were measured using linear variable differential transformers (LVDTs), while loads were measured using calibrated load cells that served as loading rods for the test. The specimens were loaded continuously until failure, with loading rates meeting the requirements outlined in ASTM A944.



**Figure 2.1:** Beam-end test specimen (Aryal et al. 2023)



**Figure 2.2:** Beam-end test specimen and test frame

## CHAPTER 3: TEST RESULTS

Six specimens - three uncoated and three TECR - were tested at the age of six days, while the remaining six specimens were tested at the age of seven days over a four-hour period on each day. The average concrete compressive strength was 4840 psi at six days and 5010 psi at seven days. The test results are shown in Table 3.1.

**Table 3.1:** Beam-End Test Results

Specimen ID	$f_{cm}$ psi	$\ell_d$ in.	Top Cover in.	Side Cover 1 in.	Side Cover 2 in.	Average Side Cover in.	Bond Force kips
UC1	4840	10.19	1.81	4.31	4.13	4.22	24.38
UC2		10.50	1.81	4.25	4.19	4.22	23.48
UC3		9.94	1.75	4.19	4.13	4.16	21.07
TECR1		10.00	1.63	4.31	4.06	4.19	22.16
TECR2		10.19	1.75	4.31	4.06	4.19	22.99
TECR3		10.00	1.69	4.06	4.31	4.19	22.46
UC4	5010	10.19	1.63	4.31	4.06	4.19	22.72
UC5		10.19	1.81	4.19	4.13	4.16	22.10
UC6		10.13	1.75	4.19	4.19	4.19	22.69
TECR4		10.06	1.69	4.06	4.25	4.16	22.56
TECR5		10.06	1.63	4.06	4.19	4.13	23.87
TECR6		9.94	1.88	4.06	4.25	4.16	22.77

**Notation:**

- Specimen ID notation example: UC1, the letter represents the type of bar (UC for uncoated and TECR for textured-epoxy-coated) and the number represents the specimen designation with the bar type
- $f_{cm}$ : Average concrete compressive strength at testing
- $\ell_d$ : Actual measurement of bonded length (measured post failure)

The maximum bond forces (bond strengths) of the specimen are normalized with respect to a concrete compressive strength of 5000 psi assuming that the bond forces are proportional to the compressive strength raised to the  $\frac{1}{4}$  power (Darwin et al. 1996, ACI Committee 408 2003). The normalized bond strengths of the specimens are shown in Table 3.2. The mean bond strength of the specimens containing the TECR is 100.3 percent of the mean bond strength of the specimens

containing uncoated bars. The specimens with TECR had bond strengths ranging from 22.34 to 23.85 kips, with a mean bond strength of 22.89 kips, a standard deviation of 0.501 kips, and a coefficient of variation of 0.022. The specimens containing uncoated bars had bond strengths ranging from 21.25 to 24.58 kips, with a mean bond strength of 22.83 kips, a standard deviation of 1.071 kips and a coefficient of variation of 0.047. The mean bond strength for the specimens with TECR differs by just 0.06 kips from the mean bond strength of the specimens with uncoated bars. When analyzed using Student’s *t*-test (suitable for analyzing small data sets), the *p*-value is 0.916,<sup>1</sup> indicating that the difference in strength is not statistically significant.

**Table 3.2:** Normalized Bond Strengths

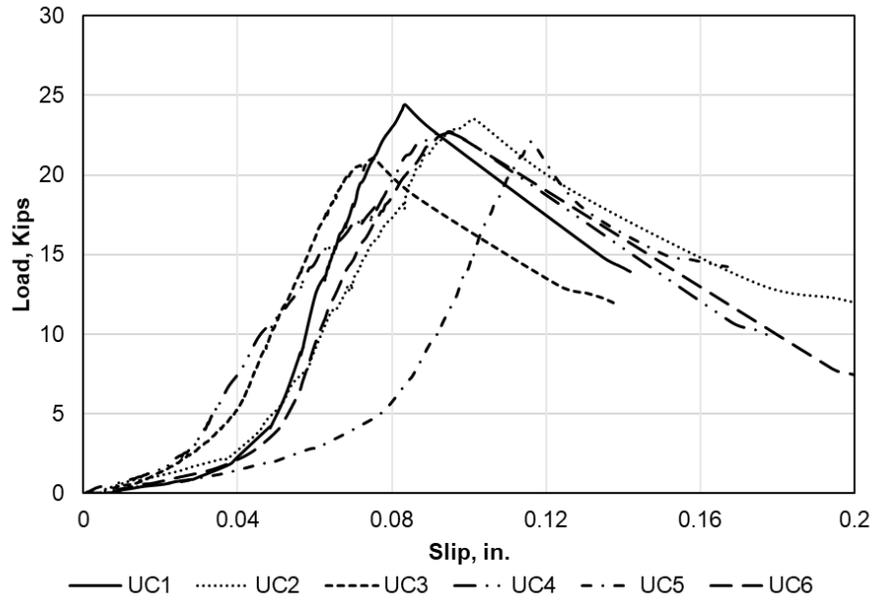
Specimen	Force, kips	
	UC	TECR
<b>1</b>	24.58	22.34
<b>2</b>	23.68	23.18
<b>3</b>	21.25	22.64
<b>4</b>	22.71	22.55
<b>5</b>	22.09	23.85
<b>6</b>	22.68	22.76
<b>Avg.</b>	22.83	22.89
<b>Std. Dev.</b>	1.071	0.501
<b>COV</b>	0.047	0.022
	Mean TECR/UC	100.3%

Bar slip at the loaded end of the specimens is shown in Figures 3.1 and 3.2, and slip at peak load is summarized in Table 3.3. For the TECR specimens, slip at peak load ranged from 0.0728 in. to 0.0970 in., with a mean of 0.0846 in., a standard deviation of 0.0082 in., and a coefficient of variation of 0.097. For the uncoated bar specimens, slip at peak load ranged from 0.0754 in. to

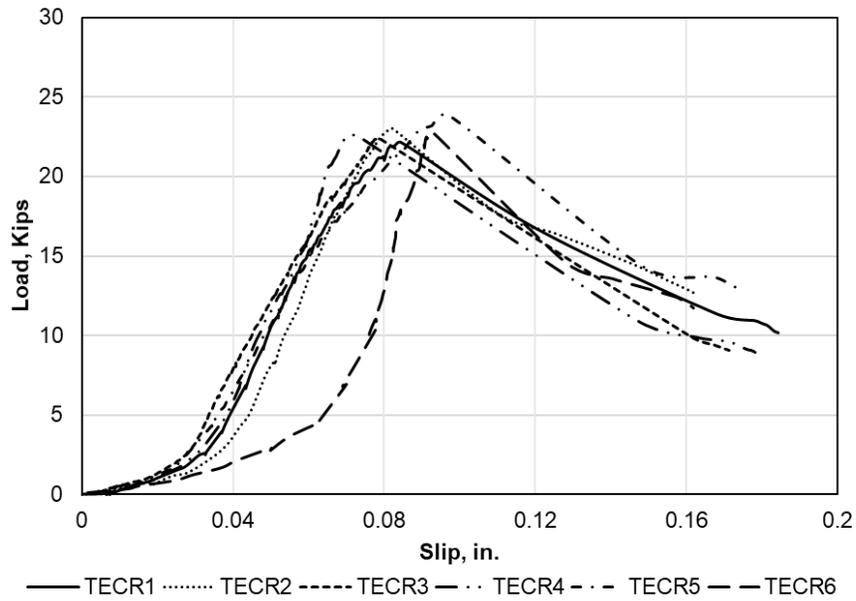
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<sup>1</sup>  $p > 0.05$  indicates that the difference between two means is not statistically significant.

0.1164 in., with a mean of 0.0945 in., a standard deviation of 0.0130 in., and a coefficient of variation of 0.138.



**Figure 3.1:** Load versus loaded end slip for uncoated bar specimens



**Figure 3.2:** Load versus loaded end slip for textured-epoxy-coated bar specimens

**Table 3.3:** Loaded End Slip at Peak Load

<b>Specimen</b>	<b>Slip at Peak Load (in.)</b>	
	<b>UC</b>	<b>TECR</b>
<b>1</b>	0.0836	0.0845
<b>2</b>	0.1016	0.0824
<b>3</b>	0.0754	0.0783
<b>4</b>	0.0945	0.0728
<b>5</b>	0.1164	0.0970
<b>6</b>	0.0956	0.0927
<b>Avg.</b>	0.0945	0.0846
<b>Std. Dev.</b>	0.0130	0.0082
<b>COV</b>	0.138	0.097

Given that the relative bond strength of the TECR bars to that of uncoated bars was 100.3% of the bond strength of uncoated bars, it seems reasonable to consider the two types of reinforcement as having the same bond strength. Considering that there will be variation in the bond strengths of the two types of reinforcement, a lower bound on the relative bond strength of TECR of 99.5% to qualify as having the same bond strength as uncoated bars would be appropriate.

## **CHAPTER 4: SUMMARY AND CONCLUSIONS**

### **4.1 Summary**

Twelve beam-end specimens, consisting of six uncoated/textured-epoxy-coated reinforcement (TECR) pairs, were cast and tested in accordance with ASTM A944 and A1124 to compare the bond strength of TECR with that of uncoated bars. The texturing surface treatment material is produced by Sherwin-Williams. The test results are used to develop recommendations for the bond qualification of the textured coating.

### **4.2 Conclusions**

The following conclusions are based on the test results presented in this report.

1. The textured-epoxy-coated bars (TECR) provided a bond strength equal to 100.3 percent of that exhibited by uncoated bars from the same heat of steel.
2. The difference in bond strength between TECR and uncoated bars is not statistically significant.

### **4.3 Recommendations**

Textured coating should be qualified as providing bond strength equivalent to that of uncoated bars if the relative bond strength is not less than 99.5% of that of uncoated bars from the same heat of steel in the beam-end test.

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