Performance of Reinforcement Bar Mechanical Couplers at Low, Medium, and High Strain Rates

Stephen P. Rowell

Research General Engineer

Geotechnical and Structures Laboratory

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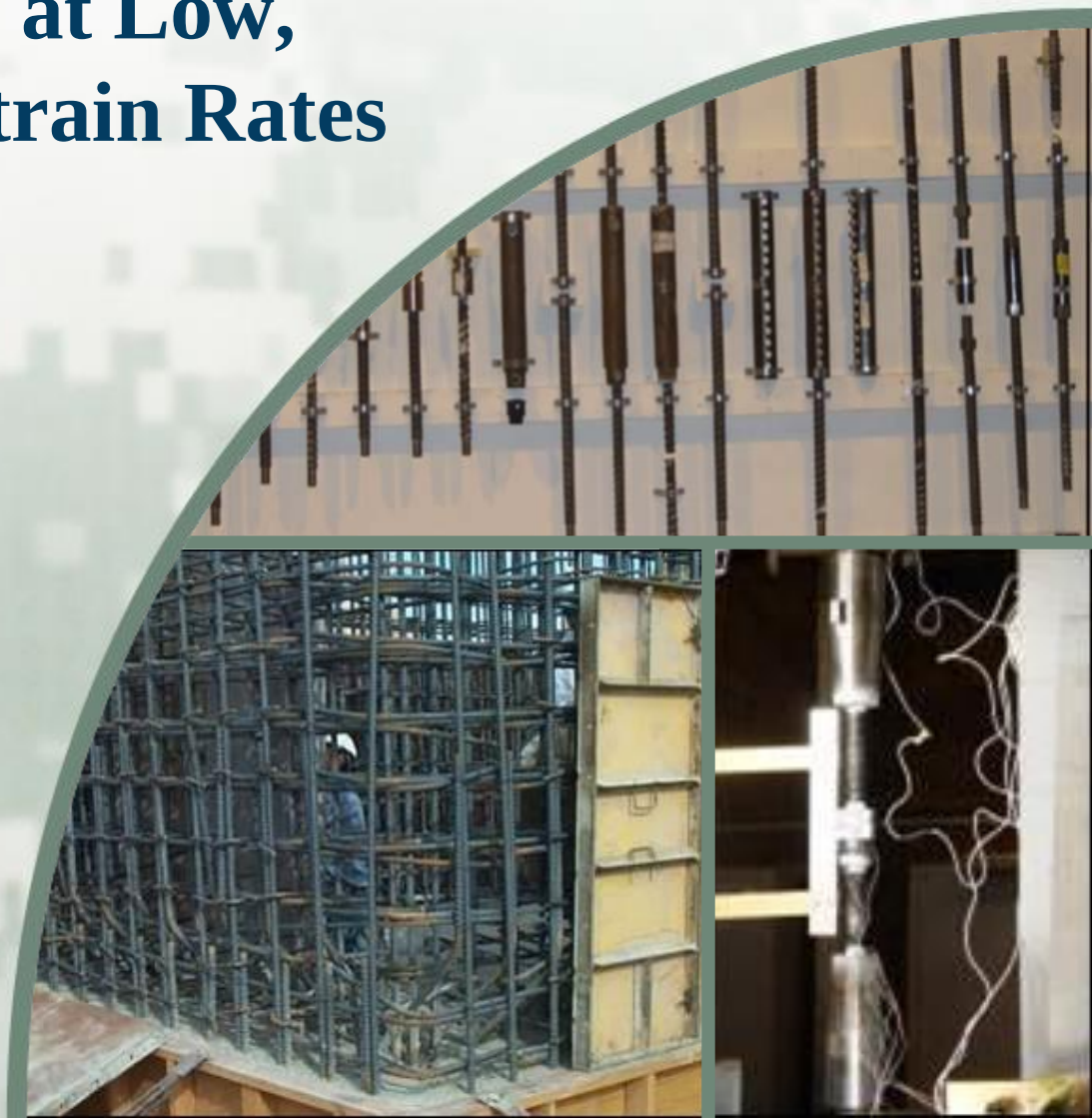

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Objectives

- Background and review of previous coupler testing
- UFC 3-340-02 criteria and coupler acceptance prior to Change 1
- UFC 3-340-02 criteria and coupler acceptance after Change 1
- Examples of acceptance comparisons
- Path forward for testing and validation of couplers

Background

- Unified Facilities Criteria (UFC) 3-340-02, "Structures to Resist the Effects of Accidental Explosions," Change 1 (1 July 14) implemented a new testing protocol and performance criteria for mechanical couplers (UFC 3-340-02 formerly designated as Army TM 5-1300/NAVFAC P-397/AFR 88-22 (TM 5-1300)).

- New criteria applicable to flexural steel in reinforced concrete elements designed and constructed to satisfy DoD explosives safety requirements.

- Flexural reinforcement steel is lap spliced, often creating congestion.

- In 1971 and again in 2009 several types of splices were tested under dynamic load conditions at the Engineer Research and Development Center (ERDC).

- Several types of mechanical couplers have been tested and validated to develop the strength of reinforcing steel for cyclic loading and strain rates expected during earthquakes.

- No mechanical couplers have been shown to meet the previous UFC 3-340-02 /TM 5-1300 requirement "Develop ultimate dynamic tensile strength of reinforcement without reducing its ductility".

Review of Previous Work

1971 Research

- Mr. W. J. Flathau
- "Dynamic Test of Large Reinforcing Bar Splices"
- Obj. various splices

- Experiment matrix:
  - Size # 11 bar (1.41" nom. dia.)
  - 3 strain rates
  - 0.005, 0.05, 3.0 in/in/sec
  - As-rolled grade 60
  - Machined grades 60 & 75
  - Butt-welded splices 60 & 75
  - Thermite-welded spl. 60 & 75
  - Cadweld splices 60 & 75

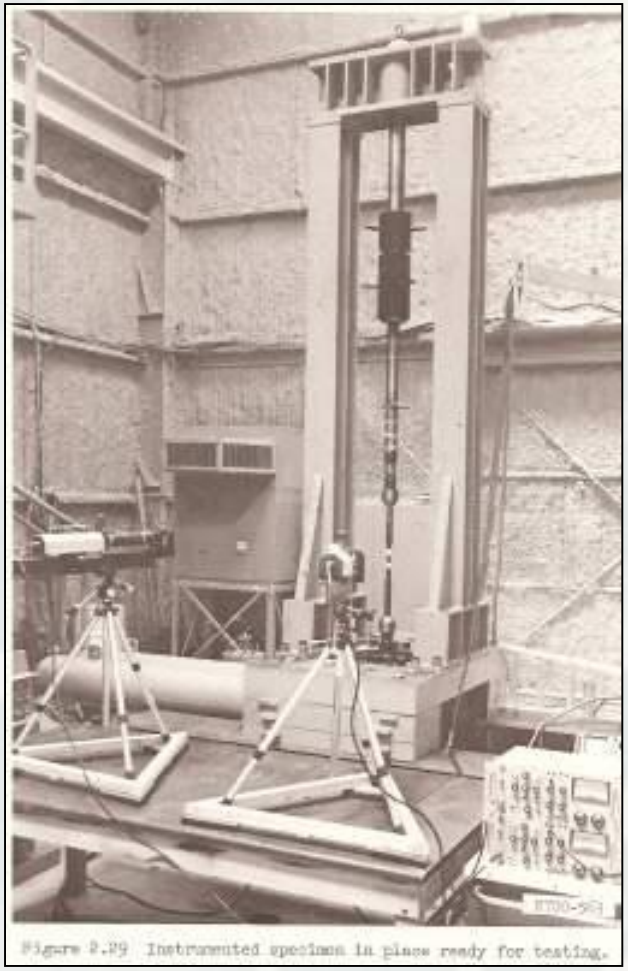


Figure 2.29 Instrumented specimen in place ready for testing.

2009 Research

- Completed in September 2009
- "High Strain Rate Testing of Mechanical Couplers"
- Obj. Mechanical couplers

- Experiment matrix:
  - Size # 10 bar (1.27" nom. dia.)
  - Three strain rates
  - 0.005, 0.05, 3.0 in/in/sec
  - As-rolled bars grade 60 & 75
  - Machined bars grade 60
  - "Upset" & "Grouted sleeve" sys
  - "Shear screws" & "Threaded" sys
  - "Threaded bar" sys

Splices Tested in WES TR-N-71-2 (Flathau 1971)

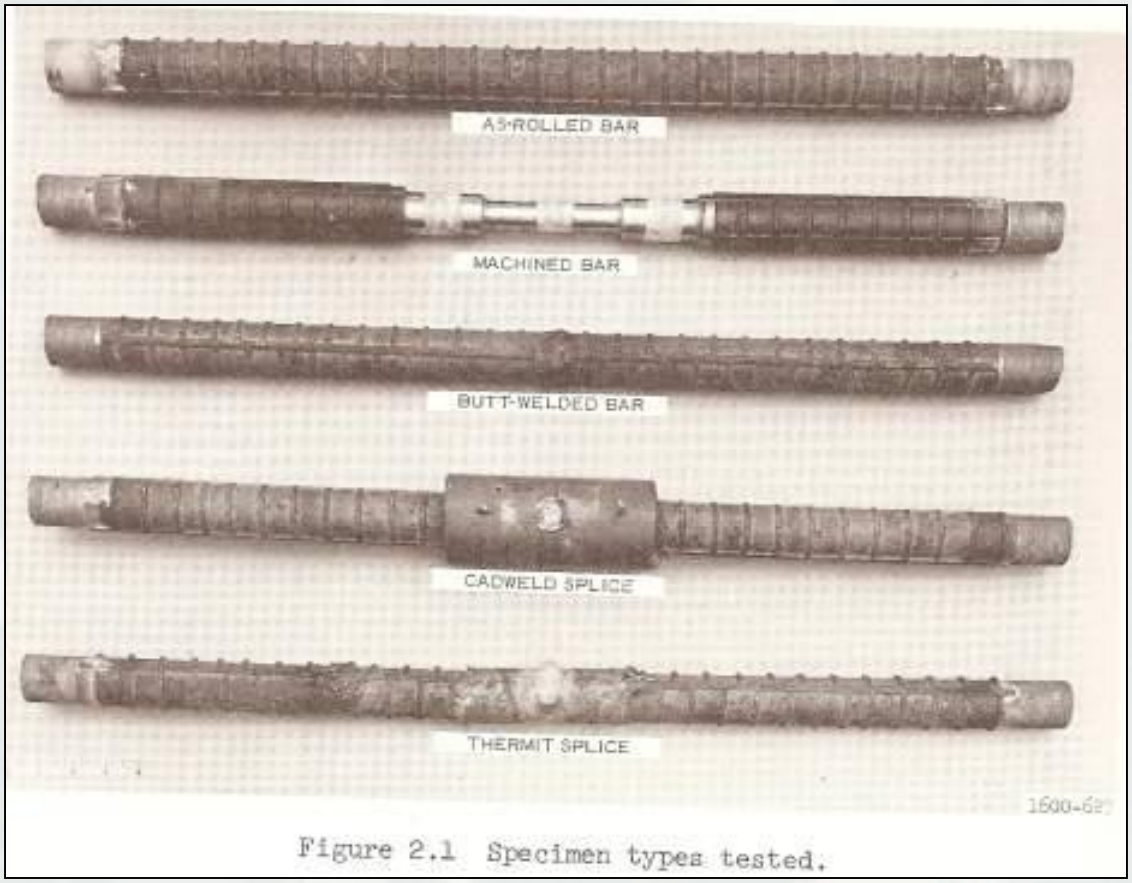
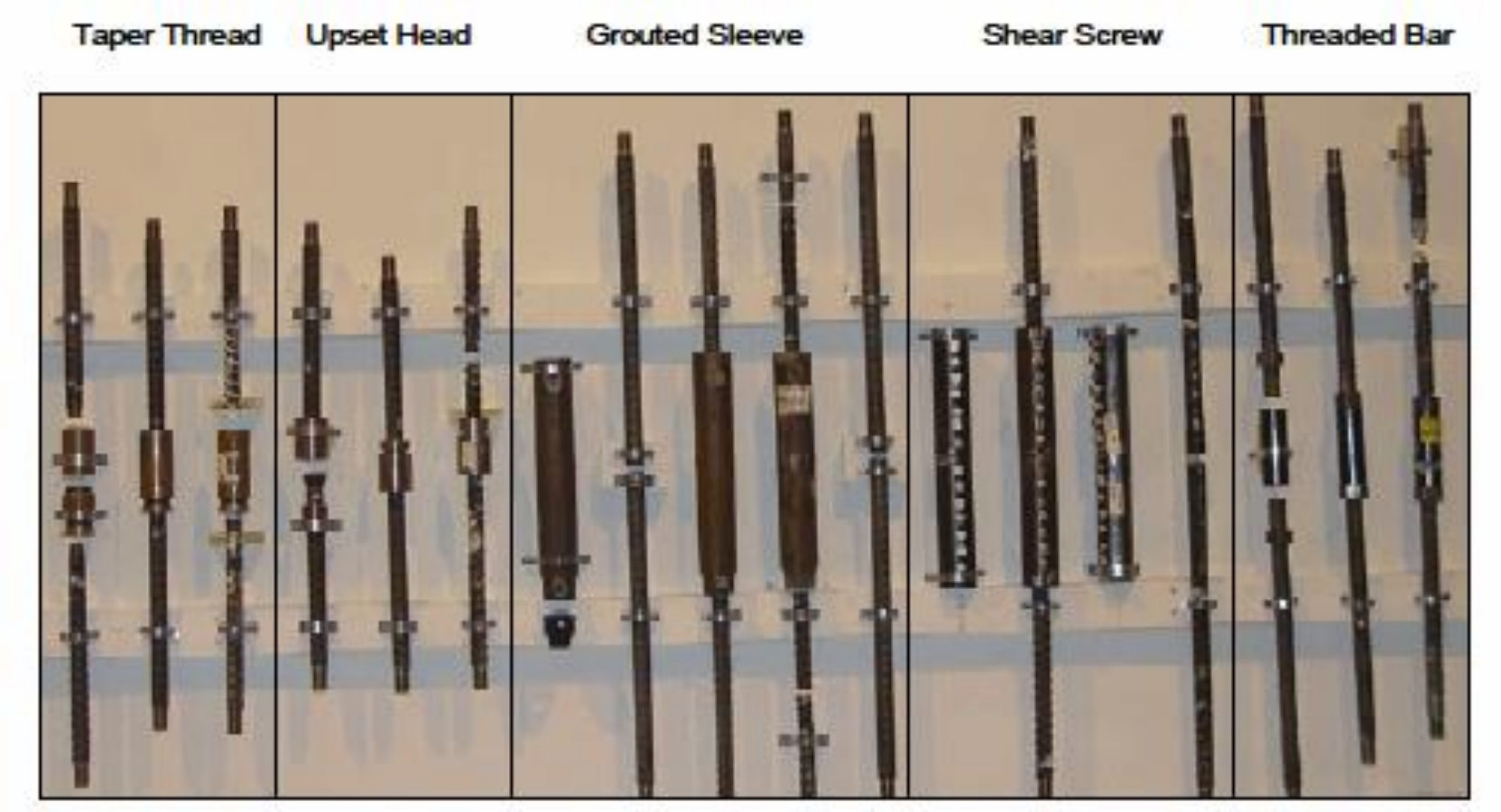


Figure 2.1 Specimen types tested.

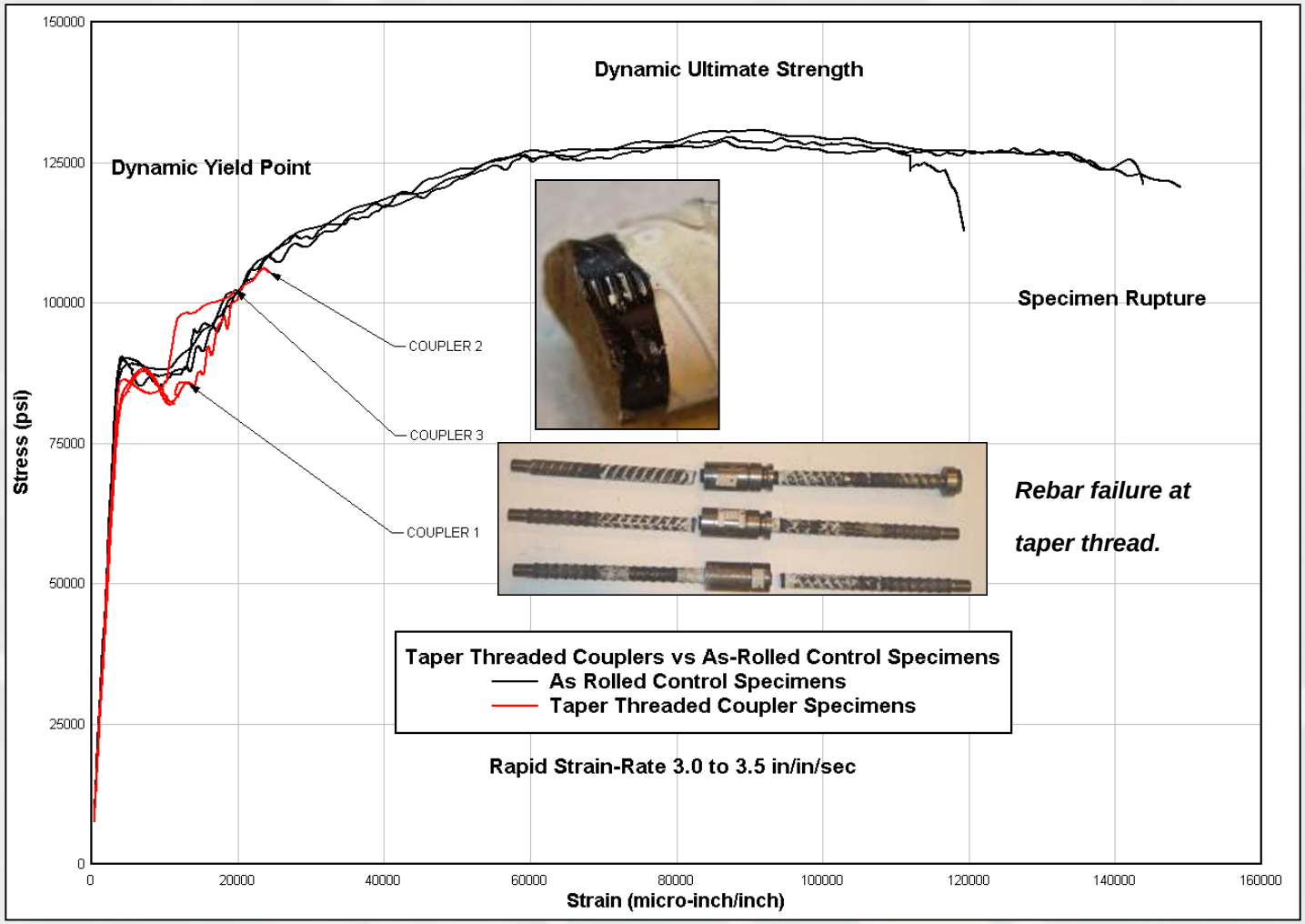
Mechanical Couplers Tested in ERDC-TR-09-8 (Rowell et al. 2009)



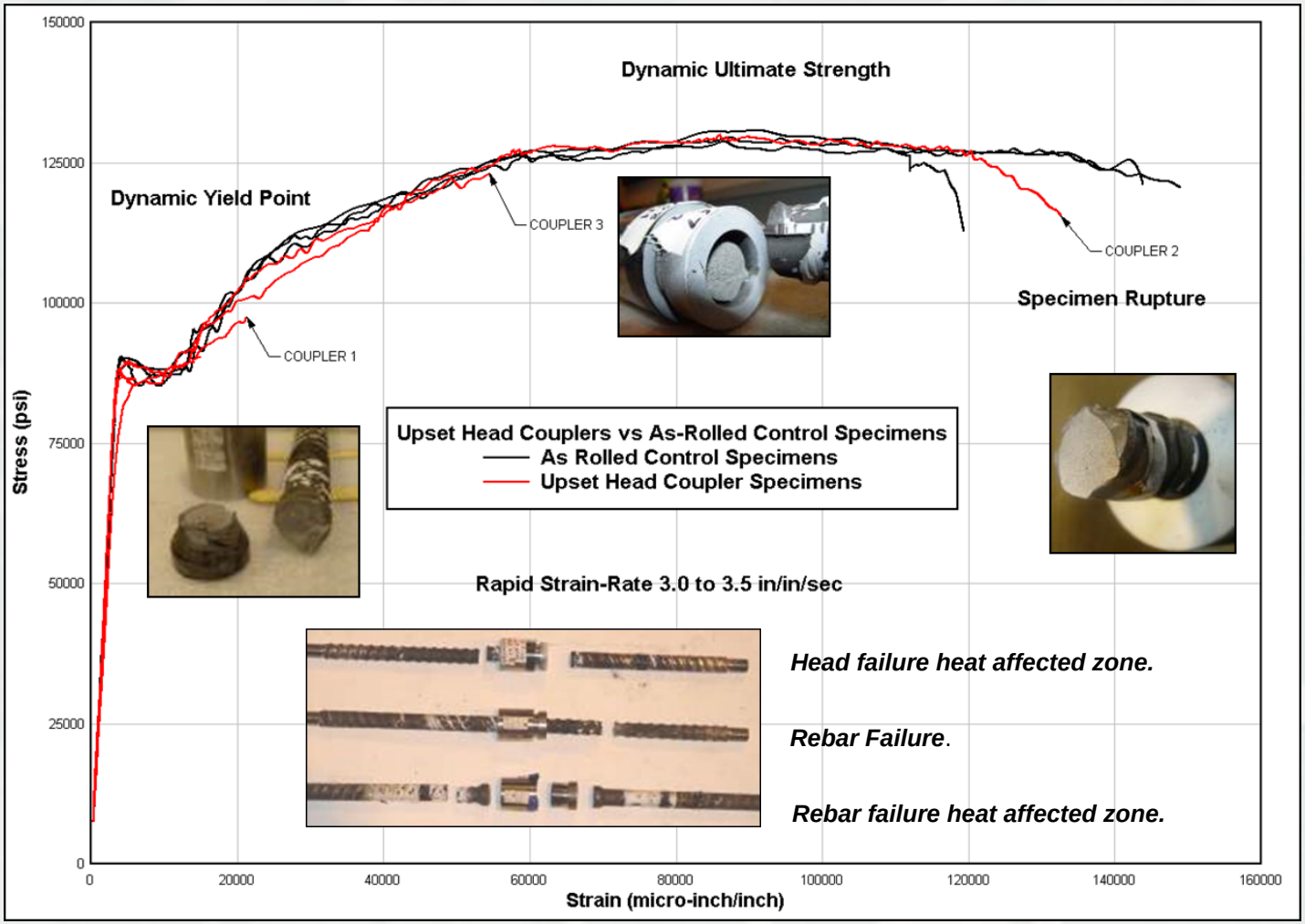
UFC 3-340-02 - Mechanical Coupler Acceptance Criteria

Prior to Change 1 of UFC 3-340-02, the criteria given in Section 4-21.8 stated that devices for mechanical splices of reinforcement may be used for end anchorage and splices in reinforcement, if they are capable of developing the ultimate dynamic tensile strength of the reinforcement without reducing its ductility.

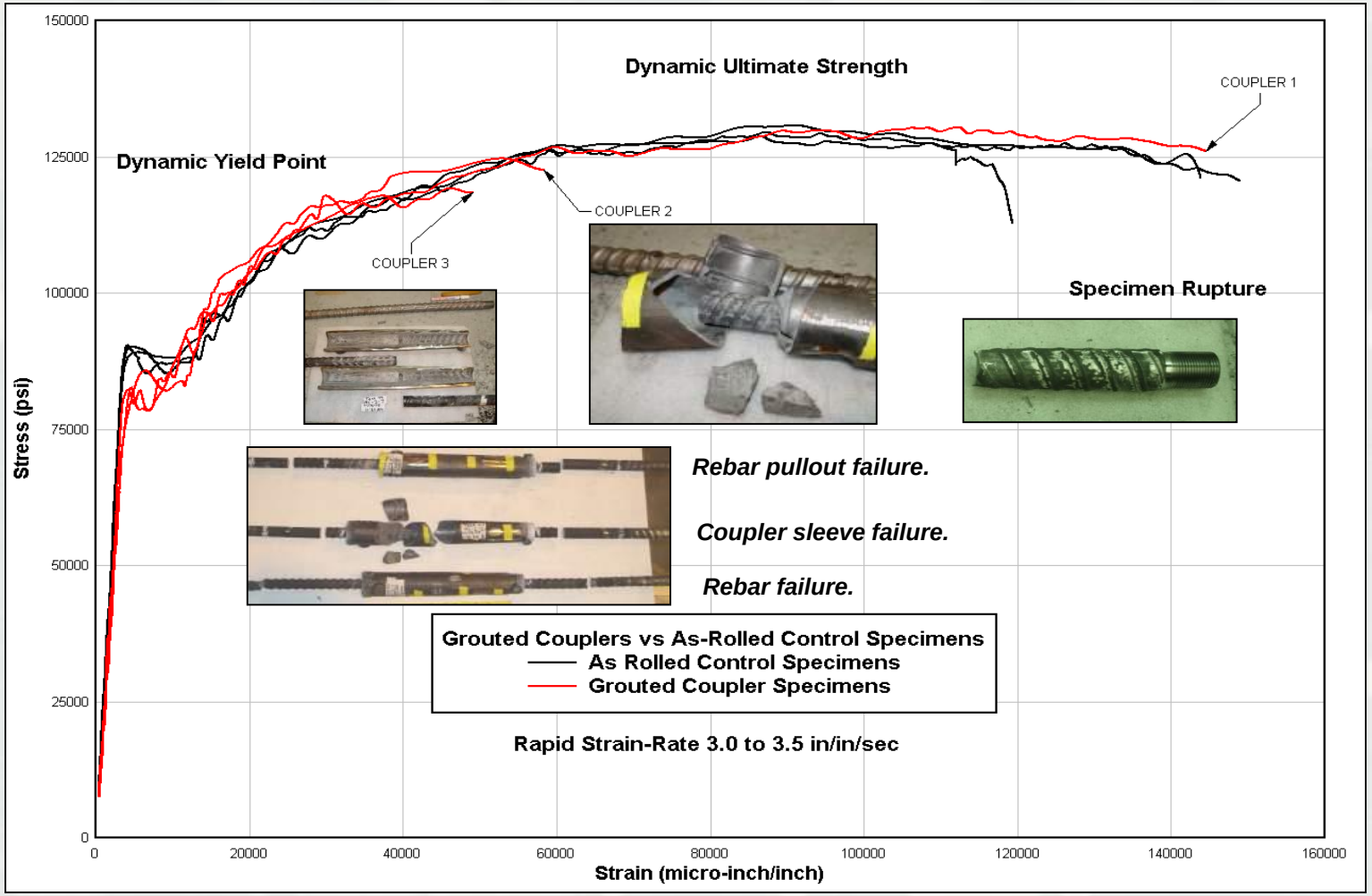
Results for Taper Thread Coupler



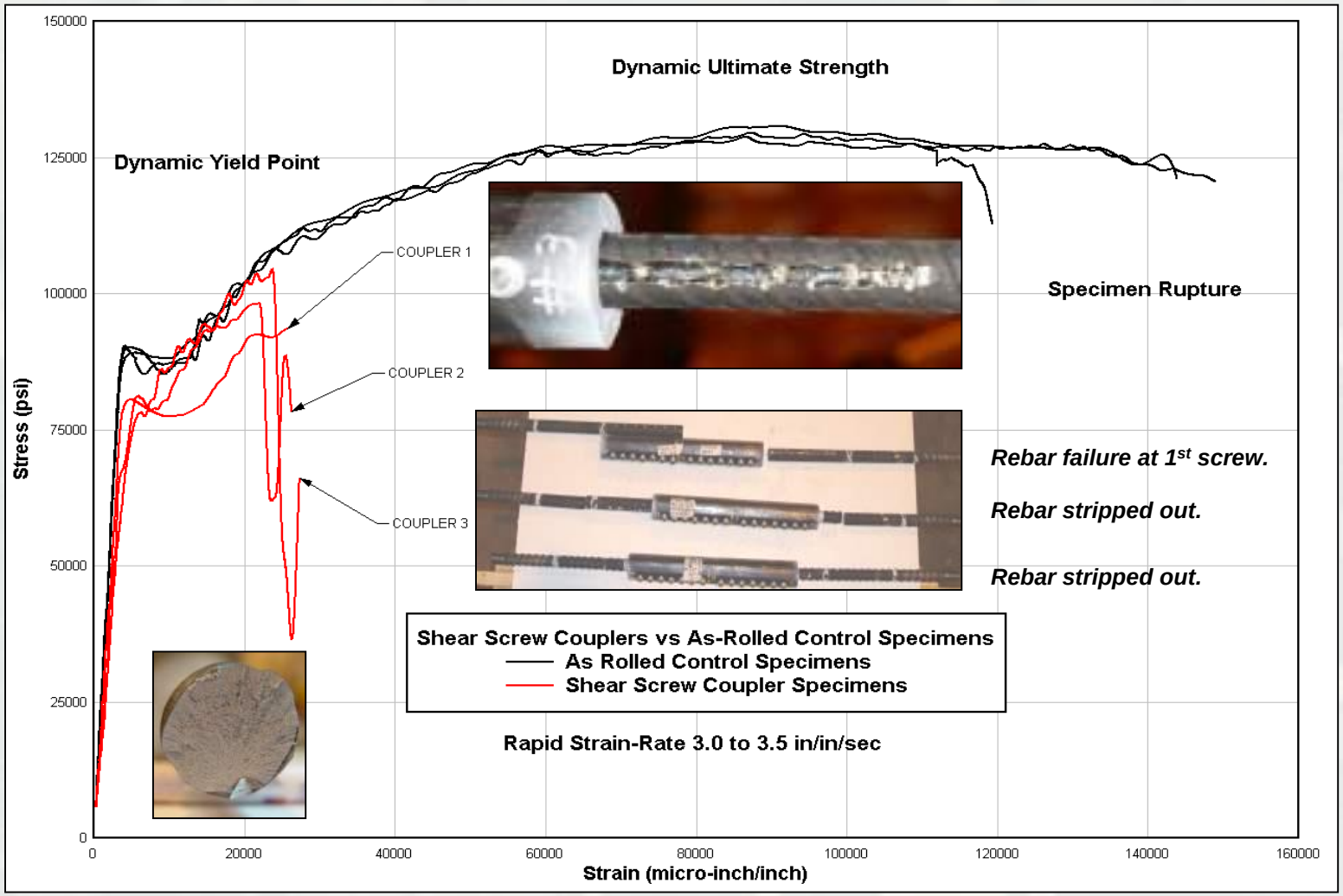
Results for Upset Head Coupler



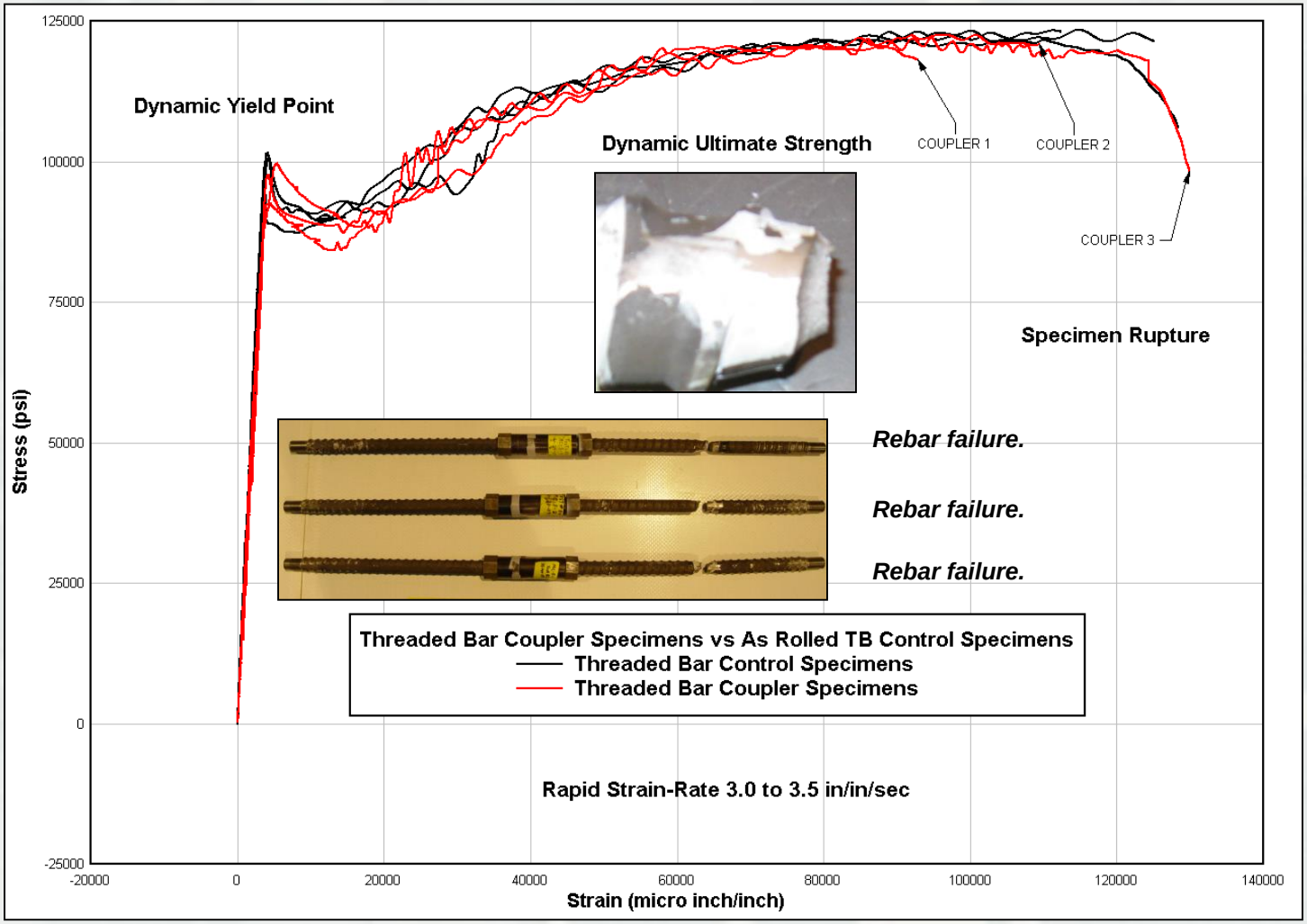
Results for Grouted Sleeve Coupler



Results for Shear Screw Coupler



Results for Threaded Bar Coupler



UFC 3-340-02 Change 1 - Mechanical Coupler Acceptance Criteria

Change 1 to the UFC 3-340-02 revised Section 4-21.8 to provide additional acceptance criteria. Section 4-21.8 now states that to determine the adequacy of the device, a minimum of three validation tests shall be performed at each strain-rate (low, intermediate, rapid), as defined in ERDC-TR-09-8 (Rowell et al. 2009); thus, a minimum of 9 tests are required. For acceptance of a device, all tests shall demonstrate the development of a minimum 3% strain in the rebar. If a maximum of one of the three tests at each strain rate fails to demonstrate the development of a minimum 3% strain in the rebar, two additional tests may be conducted; each of the two additional tests must demonstrate the development of a minimum 3% strain in the rebar.

Taper Thread Coupler Comparison

Specimen Category	Specimen Number	Yield Stress (psi)	Yield Strain (µin./in.)	Dynamic Ultimate Strength (psi)	Maximum Strain (µin./in.)	Ductility Ratio	Elongation %	Strain Rate (in./in./sec)
AR-Rap	**Average**	**89,800**	**4,700**	**129,600**	**138,000**	**29.5**	**13.8**	**3.2**
TTC1	MC-4-1	86,400	5,900	87,800	13,300	2.3	1.3	3
TTC2	MC-4-2	86,900	5,700	106,000	24,300	4.3	2.4	3
TTC3	MC-4-3	86,300	4,400	102,400	19,700	4.5	2	3.7
TTC	Average	86,500	5,300	98,800	19,100	3.7	1.9	3.2
AR-Inter	**Average**	**74,800**	**5,300**	**119,500**	**105,000**	**19.9**	**10.5**	**0.064**
TTC4	MC-4-4	73,000	5,100	96,900	25,000	4.9	2.5	0.057
TTC5	MC-4-5	73,300	5,100	120,700	101,800	19.8	10.1	0.058
TTC6	MC-4-6	73,100	5,400	11,200	37,500	6.9	3.8	0.065
TTC	Average	73,100	5,200	109,200	54,800	10.5	5.5	0.06
AR-Slow	**Average**	**70,800**	**5,200**	**117,000**	**100,800**	**19.4**	**10.1**	**0.0037**
TTC7	MC-4-7	69,800	5,000	118,000	121,900	23.8	12.2	0.003
TTC8	MC-4-8	66,800	5,000	114,700	121,900	24.4	12.2	0.003
TTC9	MC-4-9	70,700	5,000	118,600	98,200	19.5	9.8	0.003
TTC	Average	69,100	5,000	117,100	114,000	22.6	11.4	0.003

Upset Head Coupler Comparison

Specimen Category	Specimen Number	Yield Stress (psi)	Yield Strain (µin./in.)	Dynamic Ultimate Strength (psi)	Maximum Strain (µin./in.)	Ductility Ratio	Elongation %	Strain-Rate (in./in./sec)
AR-Rap	**Average**	**89,800**	**4,700**	**129,600**	**138,000**	**29.5**	**13.8**	**3.2**
UHC3	MC-1-3	85,300	5,900	97,500	21,300	3.6	2.1	3.2
UHC5	MC-1-5	89,500	5,200	129,900	132,600	25.5	13.3	3.1
UHC12	MC-1-12	88,300	3,800	123,100	54,448	14.3	5.4	3.2
UHC	Average	87,700	5,000	116,800	69,464	14.5	6.9	3.2
AR-Inter	**Average**	**74,800**	**5,300**	**119,500**	**105,000**	**19.9**	**10.5**	**0.064**
UHC6	MC-1-6	71,700	5,500	120,900	76,600	14	7.6	0.068
UHC7	MC-1-7	73,600	5,200	119,300	69,900	13.5	6.9	0.059
UHC8	MC-1-8	74,800	5,200	114,000	44,700	8.6	4.4	0.058
UHC	Average	73,400	5,300	118,100	63,700	12	6.3	0.062
AR-Slow	**Average**	**70,800**	**5,200**	**117,000**	**100,800**	**19.4**	**10.1**	**0.0037**
UHC9	MC-1-9	x	x	x	x	x	x	x
UHC10	MC-1-10	70,900	5,000	119,300	111,800	22.3	11.2	0.003
UHC11	MC-1-11	71,100	5,000	119,000	101,600	20.2	10.2	0.003
UHC	Average	71,000	5,000	119,200	106,700	21.3	10.7	0.003

Grouted Sleeve Coupler Comparison

Specimen Category	Specimen Number	Yield Stress (psi)	Yield Strain (µin./in.)	Dynamic Ultimate Strength (psi)	Maximum Strain (µin./in.)	Ductility Ratio	Elongation %	Strain Rate (in./in./sec)
AR-Rap	**Average**	**89,800**	**4,700**	**129,600**	**138,000**	**29.5**	**13.8**	**3.2**
GSC1	MC-2-1	85,700	6,400	130,300	144,500	22.5	14.5	3.5
GSC2	MC-2-2	82,600	4,600	124,700	58,400	12.7	5.8	3
GSC3	MC-2-3	82,300	4,200	119,200	49,000	11.6	4.9	3.2
GSC	Average	83,600	5,100	124,700	84,000	15.6	8.4	3.2
AR-Inter	**Average**	**74,800**	**5,300**	**119,500**	**105,000**	**19.9**	**10.5**	**0.064**
GSC4	MC-2-4	73,900	5,500	122,300	89,100	16.1	8.9	0.064
GSC5	MC-2-5	74,700	5,400	122,100	85,900	16	8.6	0.059
GSC6	MC-2-6	74,000	5,300	121,600	82,400	15.4	8.2	0.06
GSC	Average	74,200	5,400	122,000	85,800	15.8	8.6	0.061
AR-Slow	**Average**	**70,800**	**5,200**	**117,000**	**100,800**	**19.4**	**10.1**	**0.0037**
GSC7	MC-2-7	71,000	53,000	115,800	65,800	12.5	6.6	0.004
GSC8	MC-2-8	70,400	5,000	114,000	67,400	11.6	5.7	0.003
GSC9	MC-2-9	69,200	5,200	113,900	60,000	11.6	6	0.004
GSC	Average	70,200	5,100	114,500	61,100	11.9	6.1	0.004

Shear Screw Coupler Comparison

Specimen Category	Specimen Number	Yield Stress (psi)	Yield Strain (µin./in.)	Dynamic Ultimate Strength (psi)	Maximum Strain (µin./in.)	Ductility Ratio	Elongation %	Strain Rate (in./in./sec)
AR-Rap	**Average**	**89,800**	**4,700**	**129,600**	**138,000**	**29.5**	**13.8**	**3.2**
SSC1	MC-3-1	80,500	4,800	93,600	25,700	5.3	2.6	3.5
SSC2	MC-3-2	81,100	5,900	98,300	26,300	4.5	2.6	3.2
SSC3	MC-3-3	78,200	6,200	104,500	27,300	4.4	2.7	3.8
SSC	Average	80,000	5,600	98,800	26,400	4.7	2.6	3.5
AR-Inter	**Average**	**74,800**	**5,300**	**119,500**	**105,000**	**19.9**	**10.5**	**0.064**
SSC4	MC-3-4	72,900	5,600	97,100	26,000	4.7	2.6	0.065
SSC5	MC-3-5	73,300	5,600	116,800	62,800	11.3	6.3	0.062
SSC6	MC-3-6	72,500	5,500	86,200	15,700	2.8	1.6	0.065
SSC	Average	72,900	5,600	100,000	34,800	6.3	3.5	0.064
AR-Slow	**Average**	**70,800**	**5,200**	**117,000**	**100,800**	**19.4**	**10.1**	**0.0037**
SSC7	MC-3-7	68,800	5,400	80,600	16,700	3.1	1.7	0.004
SSC8	MC-3-8	69,700	5,000	95,800	27,000	5.4	2.7	0.003
SSC9	MC-3-9	69,300	5,200	81,500	17,600	3.4	1.8	0.004
SSC	Average	69,300	5,200	86,000	20,400	4	2.1	0.004

Threaded Bar Coupler Comparison

Specimen Category	Specimen Number	Yield Stress (psi)	Yield Strain (µin./in.)	Dynamic Ultimate Strength (psi)	Maximum Strain (µin./in.)	Ductility Ratio	Elongation %	Strain Rate (in./in./sec)
AR-Rap	**Average**	**99,000**	**4,000**	**122,800**	**122,000**	**30.2**	**12.2**	**3.2**
TBC1	MC-5-1	92,600	4,400	120,900	92,900	21.2	9.3	3.2
TBC2	MC-5-2	99,700	5,300	122,500	109,700	21.7	11	3.4
TBC3	MC-5-3	97,700	4,200	122,000	130,000	31.1	12.9	3.3
TBC	Average	96,400	4,600	121,800	110,800	24.7	11.1	3.3
AR-Inter	**Average**	**81,500**	**3,800**	**115,200**	**115,200**	**31**	**11.5**	**0.052**
TBC4	MC-5-4	80,900	4,100	113,700	109,900	26.9	11	0.048
TBC5	MC-5-5	80,700	3,700	113,300	109,100	29.4	10.9	0.05
TBC6	MC-5-6	81,200	4,900	113,900	92,900	19	9.3	0.05
TBC	Average	80,900	4,200	113,700	104,000	25.1	10.4	0.049
AR-Slow	**Average**	**76,100**	**4,000**	**110,400**	**108,600**	**27.5**	**10.9**	**0.0031**
TBC7	MC-5-7	x	x	x	x	x	x	x
TBC8	MC-5-8	80,300	4,500	111,500	69,000	15.2	6.9	0.003
TBC9	MC-5-9	80,900	3,400	111,700	65,900	19.6	6.5	0.003
TBC	Average	80,600	3,900	111,600	67,400	17.4	6.7	0.003

Conclusions

- UFC 3-340-02 Change 1:

  - Allows for a more definitive test procedure that more adequately determines suitability of mechanical couplers for use in dynamic loading applications.

- Under the previous criteria:

  - Two coupler systems appear adequate for low strain-rate service only.
  - No couplers passed for full service at all three strain-rates.

- Under the Change 1 criteria:

  - One out of five coupler systems tested passed without further testing.
  - Two out of five required further testing to determine adequacy.
  - Two out of five failed to meet the new criteria and require no further testing.

Path Forward for Testing and Validation of Couplers

Mechanical devices that satisfy the validation test requirements of this section may be used for end anchorage and splices in reinforcement in elements under certain conditions. Mechanical splices may only be used in elements that are designed for a support rotation of 6 degrees or less and are not susceptible to concrete spalling (see section 4-55).

Path Forward for Testing and Validation of Couplers

To ensure consistency in testing procedures for different mechanical coupler systems, all dynamic validation tests shall be performed by the U.S. Army Engineer Research and Development Center (ERDC) in accordance with the procedure presented in ERDC-TR-09-8, "High Strain-Rate Testing of Mechanical Couplers."

Rebar may be grouped in one of two groups of rebar sizes (no. 4, 5, 6, 7 and no. 8, 9, 10, 11). Success of a mechanical device on a rebar size within its group shall be considered applicable to all rebar sizes in that group.

Path Forward for Testing and Validation of Couplers

Mechanical splices shall be located in regions of low stress where the area of reinforcement provided is a least twice that required. In addition, mechanical splices of adjacent parallel reinforcing bars shall be staggered by at least their splice length, calculated in accordance with ACI 318."

Questions?

Stephen P. Rowell
Research General Engineer
Engineer Research and Development Center
Vicksburg, MS

601-634-2533