ELECTRIC POWER RESEARCH INSTITUTE

Advanced Nuclear Technology: Investigating Mechanical Splicing of Reinforcing Steel

2017 TECHNICAL REPORT

Advanced Nuclear Technology: Investigating Mechanical Splicing of Reinforcing Steel

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ABSTRACT

In many reinforced concrete structures, it is often necessary to have reinforcement in lengths longer than are typically available from steel mills. When the increased congestion and material caused by a traditional lap splice is undesirable or impractical, engineers must turn to mechanical splices. Mechanical splices use several ways of interlocking to allow force transfer between spliced bars over much shorter lengths than required for a lap splice, saving material cost and easing reinforcement congestion. In some cases and as a result of easing reinforcement congestion, mechanical splicing can speed the placement of reinforcing steel. In addition, the reduction in congestion reduces the likelihood of concrete defects that cause construction delays and additional costs. Several types of mechanical splices are available, but few resources exist to aid the engineer or contractor in the selection of an optimal splice for a project. Specific aspects of a project, such as a close reinforcement spacing or a rapid construction schedule, can make some types of mechanical splices better choices than others.

This report describes the examination of 91 mechanical splices from 29 domestic and international companies. Splices were sorted into 22 categories based on the splice configuration and method of interlock with the bars being spliced. For each category of splice, the mechanism of force transfer is described, the properties of the splice in terms of bar size and grade of reinforcing steel are cataloged (as of August 2017), and the restrictions on splice use are noted. In addition, code and regulatory provisions specific to that type of splice are noted. The barriers to entry for new and innovative splicing systems—such as an epoxy-filled splicing system—are explained, and test methods to evaluate the suitability of new splicing systems are proposed.

Keywords

Construction efficiency
Mechanical splices
Reinforced concrete
Reinforcement
Splices

EXECUTIVE SUMMARY

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PRIMARY AUDIENCE: Construction engineers, project managers, and material specifiers responsible for the specification and installation of mechanical splices for reinforced concrete

KEY RESEARCH QUESTION

Large reinforced concrete structures require reinforcing steel that is spliced in a manner that allows for continuous force transfer between bars, commonly accomplished in a lap splice. This leads to an undesirable increase in steel congestion—which can be mitigated by commercially available mechanical splices—and delays in construction activities. However, proper mechanical-splice selection provides opportunity to improve construction schedule, quality assurance, and quality control. A resource is needed to assist designers and/or material specifiers in selecting optimal mechanical splices for the specific project requirements.

RESEARCH OVERVIEW

A total of 91 splicing systems from 29 companies were reviewed and sorted into one of 22 categories based on the splice configuration and mechanism by which the mechanical splice achieves force transfer. For each category of splice, the review included splice compatibility with bar size, grade, area requirements, spacing requirements, maneuverability of the bar, and associated code and regulatory provisions. In addition to reviewing the types of splices currently on the market, domestic and international regulatory provisions regarding splices were examined, including barriers to the use of new splicing systems. Of particular interest are epoxy-filled splicing systems, which have the potential to eliminate some of the drawbacks associated with other mechanical splicing systems, potentially saving significant construction time and money. No empirical testing was performed for this research; however, recommended research studies are proposed for continuation of the findings of this literature review.

KEY FINDINGS

- A wide variety of mechanical splicing systems is available; this report helps the designer to select splice systems that are suited to the project conditions. Selection of an optimum splice system can reduce construction time and cost of the project.
- No single splicing system is best suited for all projects.
- Current code and regulatory provisions pose relatively few barriers for entry of new splicing systems. However, additional tests are needed to ensure adequate performance of new splicing systems.
- Insufficient data exist to recommend the unrestricted use of epoxy-filled splicing systems. Given the wide range of results available in the literature, specific epoxy-splice systems should be selected for thorough evaluation prior to use in a structure.
- Additional research and development is proposed to increase construction efficiency through the use of mechanical splices. The proposed research and development includes full-scale splice tests, creep tests, environmental resilience, and design guidance.

EXECUTIVE SUMMARY

WHY THIS MATTERS

This report will help designers and contractors understand the variety of mechanical splicing systems, assisting designers in selecting an optimal splice system for the project conditions. Selection of an optimum splice system can prevent costly delays, resulting in reduced construction time and cost of the project. This report also recommends tests to ensure that new splice systems being considered for use are capable of performing well over the design life of a structure, preventing potential and costly failures.

HOW TO APPLY RESULTS

This report should be used in the design and materials selection phase of a project to aid the engineer in selection of a splicing system (or systems) for the project. New splice systems should be evaluated under the recommended test protocols to better ensure that they will not be prone to failure when implemented.

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INTRODUCTION

1.1 General

Concrete structures regularly require long lengths of straight reinforcing steel, necessitating splicing of shorter lengths of bar. These splices enable a continuous force transfer between bars. For many applications, bars are connected via lap splices, obtained by overlapping two bars. Lap splices are widely used and require no additional hardware, but the presence of overlapping bars contributes to congestion and is not desirable in structures with high amounts of reinforcement. Inline connection of reinforcement can minimize congestion, but requires the use of a device that will transfer the force between bars. These devices are known as mechanical splices.

Mechanical splices allow for the direct connection of reinforcing bars by using grout-filled sleeves, threaded bars, or other means of connection; typically, the bar ends are butted against one another. Mechanical splices are particularly useful in areas with a high amount of reinforcement congestion, such as concrete containments for nuclear power plants. Mechanical splices can provide easier placement and reduce congestion compared to lap splices. In some cases, these benefits of mechanical splices have a direct impact on preventing costly construction delays by increasing the speed of placement and decreasing the need for time-consuming repairs. Additionally, certain mechanical splices are ideal for repairs and renovations, as well as connections to irregular (such as square) bars. Mechanical splices, however, have drawbacks that vary depending on the design of the splicing mechanism. Many mechanical splices require the reinforcement to be manipulated (often, rotated) to obtain a solid connection, which can be difficult. There are reinforcing bar and equipment requirements to consider, such as threading the reinforcing bars or swaging a sleeve in place. Other mechanical splices, such as grout-filled sleeves, must be left undisturbed for several hours or days until the grout has attained sufficient strength; this may limit the construction work performed nearby during this period. Much interest has been shown in the use of epoxy-filled splices, which do not require excessive manipulation of the bar and gain strength very rapidly, minimizing the disruption of construction activities. It is important, however, to establish if these types of splices are suitable for long-term use.

Although many types of mechanical splice systems exist, codes include limited information on the different types of splices and their applicability. The most recent document from the American Concrete Institute to address this information, ACI 439.3R-07 [1], was last updated in 2007 and does not address benefits and drawbacks of the different types of splices. It is, however, desirable for the designer to have a comprehensive understanding of the different types of splices and their relative advantages and disadvantages so that an efficient splicing system may be chosen for each application. Furthermore, the code and regulatory hurdles that must be overcome prior to adoption of any new splicing system should be identified, allowing for promising systems to be rapidly evaluated. This report examines the relative strengths and weaknesses of the range of mechanical splices available both domestically and internationally and analyzes the process by which new and innovative splicing system gain acceptance by regulatory and code bodies as well as by the broader engineering community.

1.2 Types and Applications of Mechanical Splices

A wide variety of mechanical splices are currently available in the marketplace. Typically, these splices involve sleeve components with a variety of ways to mechanically interlock with the reinforcing bars. Many of these mechanical splices are proprietary; however, these systems fall into general categories based on the method of interlock and intended use. ACI 439.3R-07 [1] lists 25 types of mechanical splices, categorized by the type of connection made between the reinforcing bars. Depending on the intended use and capacity of the splice to resist tensile or compressive stress, these splices are further categorized as compression, tension-compression, mechanical-lap, or dowel bar splices.

Compression splices are used where only compression forces are expected. These are rare in the market, with only two identified in the survey. Tension-compression splices are far more common. These generally have a longer sleeve length for bar engagement than compression splices. A designer selecting compression splices should consider the possibility of stress reversal that may be caused by dynamic load(s) caused by wind, earthquakes, etc. Mechanical lap splices and dowel bar splices typically fall within the grouping of tension-compression splices, but possess unique features. Mechanical lap splices involve overlapping the reinforcing bars through a sleeve. This type of splice requires less overlap for the bar than lap splicing while providing the structural integrity of a mechanical splice. Dowel bar splices are mechanical splices with flanges that attach to formwork. These are ideal for construction joints, as they eliminate protruding bars used in lap splices in adjacent members as the construction continues. These splices, however, require care to ensure proper location and orientation, because they are fixed after attachment to the formwork.

Many mechanical splices are available with specialized options for specific placement conditions. Many provide the option of transitioning bar sizes within the splice. For threaded connections requiring turning, many proprietors provide the option of positional couplers that include attachments, such as locknuts that allow the bars to be joined when only one or neither bar can be rotated. When the reinforcing bars are not able to be joined end-to-end, some mechanical splices have optional bridging splices. This allows for a specified gap length between the joined bars. Aligning the reinforcing bars is necessary and critical for many systems, but in others, minor misalignment may be acceptable.

In addition to interlock mechanism and intended use, splices are categorized based on the grade of the reinforcing steel. Mechanical splices are available for use with all commonly available grades of reinforcing steel. In in.-lb units, splices are available for Grades 60, 75, 80, 100, and 120 reinforcement under ASTM A615 [2], ASTM A706 [3], ASTM A996 [4], and ASTM A1035 [5], with bar sizes ranging from No. 3 to No. 18. In SI units, splices are available for Grades 420, 500, 670, and 800, with bar sizes ranging from No. 10 to No. 57. Special coatings for mechanical splices are available when intended for use with epoxy-coated reinforcement (ASTM A775 [6] and A934 [7]) and galvanized reinforcement (ASTM A767 [8] and A1055 [9]). There are also splices intended for use under cryogenic (extremely cold temperature) conditions and with stainless steel. Mechanical splices are also marketed specifically for use in nuclear power plant concrete containment structures. They are specified by material and code compliance (typically ACI 359, published jointly with ASME [10]).

1.3 Code Provisions

Most domestic and international building codes follow procedures similar or identical to those outlined by ACI 318 in regard to the use of mechanical splices. ACI 318-14 [11] classifies splices based on the capacity of the splice. Type 1 splices must be able to develop 125% of the yield strength of the bars being spliced, and Type 2 splices must also be able to develop the full tensile strength of the bars being spliced. The International Building Code (IBC), within the International Code Council (ICC), specifies additional performance requirements for mechanical splices. ICC AC133, Acceptance Criteria for Mechanical Splice Systems for Steel Reinforcing Bars [12], requires a measurement of elongation of the splice under tensile testing and specifying testing intervals for production splices. Various international codes also exist, but generally reference or follow ACI 318 or AC133. Specific requirements for mechanical splices in nuclear power plants are governed by ACI 359-15 [10], but only cover placement of the splice within the structure, not the design of the splice itself. A full discussion of code provisions is provided in Section 3.

1.4 Report Purpose and Scope

Currently, very little information is available to assist the designer in selecting a splice for a given application. Although ACI 439.3R-07 [1] lists and describes categories of splices, no comparison between splice types is made, and no guidance on the relative merits and weakness of each type is provided. The goal of this report is to create a source for design professionals to identify and select a mechanical splice system for a given installation. Designers who have this information readily available will be able to choose a splice that can be rapidly and reliably installed, leading to significant potential savings in construction time and cost. No specific comparisons between companies' products are made; the report focuses solely on comparing types of splices. This report is not intended to provide endorsement of any one type of splicing technology over another. Costs of mechanical splices will also not be addressed because this information is prone to fluctuation and is location dependent. An analysis of the relatively new category of epoxy-filled splices is included, and barriers to the acceptance of new splice types are identified.

Twenty-nine companies were surveyed for this report, representing both domestic and international manufacturers. A total of 91 splicing systems were identified into five types – cold-swage couplers, friction-welded couplers, screw/wedge couplers, threaded couplers, and filled couplers. Within each of these types, the splicing systems are sub-categorized into a total of 22 categories. For each of these categories, the benefits, limits, and other unique considerations are identified and listed. Domestic and international codes governing the design and use of mechanical splices are also evaluated and provisions compared.

2
MECHANICAL SPLICE DETAILS

This chapter provides details on each of the splicing systems examined in this study. Information on general use requirements and restrictions for each type of splice is presented, and the currently available range of bar sizes, grades, and splice capacity (Type 1 or Type 2) are provided. The range of bar sizes and grades are presented in in.-lb and SI units as provided by the company and are not necessarily direct conversions. For this report, standard bar sizes are considered to be those listed in ASTM A615 [2]; the availability of other bar sizes is noted where applicable. All information presented in this section was obtained from the manufacturers and is current as of August 2017 [13-41]. Code or regulatory requirements specific to a category of splice are presented in the appropriate section; general code and regulatory requirements are presented in Section 3.

2.1 Cold-Swaged Couplers

Cold-swaged couplers consist of a hollow steel tube or tubes placed over the bars to be spliced. The tubes are hydraulically pressed onto the bar on site, creating interlock. The requirement to use hydraulic press on each individual splice limits the speed of construction when using this type of splice. Detailed information on the different types of cold-swaged couplers is provided in the following sections.

2.1.1 Cold-swaged steel coupling sleeve

Cold-swaged steel splices are formed using a seamless steel tube (sleeve) as the sole component (Figure 2-1). Half of the tube length is slipped over the first bar and cold-swaged with a hydraulic press and die set before inserting the other bar and repeating on the opposing end. The reinforcing bars can be in any orientation. Although the bars must be deformed for mechanical interlock with the pressed sleeve, it is an ideal process for repair and retrofit because bar machining is not required. The die set used to compress the sleeve typically leaves indentions, helping improve mechanical interlock with the reinforcing bar. It is also convenient for bars that cannot be turned. Many of the cold-swaged coupling sleeves available are acceptable for new cast-in-place construction, as well as for repairs and renovations; some systems have been sold specifically for repair and retrofit. Cold-swaged coupling sleeves do, however, limit the minimum spacing between reinforcing bars, which is generally controlled by the field press size, and may also require staggering of the splices. The splice must be inspected after installation to ensure the reinforcement has been fully inserted into the splice and to ensure swaging along the entire sleeve length.

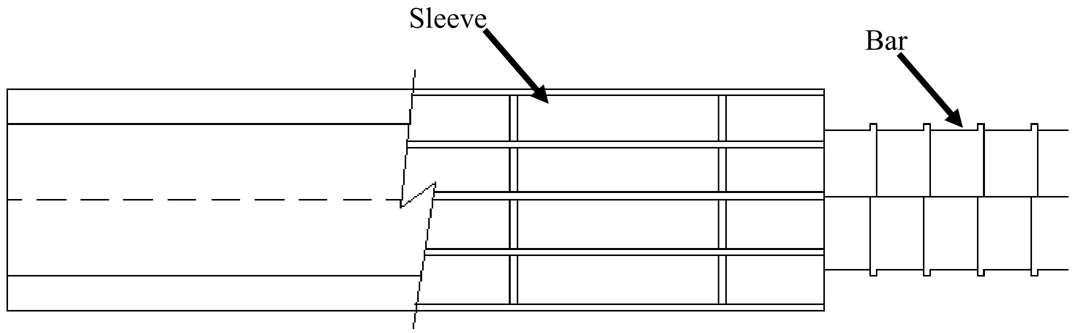

Figure 2-1
Cold-swaged coupler

Cold-swaged steel coupling sleeves represent a widely-used type of mechanical splice and are available from a variety of manufacturers. Ten cold-swaged steel sleeve splice systems are available from the companies surveyed:

- BarGrip XL®- BarSplice Products, Inc.
- GripLock™ SL- BARUS® LLC., Inc.
- Pressed Barlink SBT Coupler- Best Notch Group
- RepairGrip- Dextra Group
- FLIMU® System- DYWIDAG Systems International
- R Type- Fuji-Bolt Manufacturing Co., Ltd.
- Moment® Bargrip- Halfen-Moment
- KZ Hydraulic grip- KZ International
- Cold stamping rebar coupler- OCEPO®
- Bar Swage- Preshcon Industries PTE Ltd.

This mechanical splice system is one of the more broadly available systems investigated in this study. The surveyed products provide sleeves for standard reinforcing bar sizes ranging from No. 3 to No. 18 (in.-lb) and No. 10 to No. 57 (SI), along with other non-standard SI sizes. (The in.-lb and SI units provided here and in the following sections reflect product availability, and are not direct conversions). The listed cold-swaged sleeves are available for Grade 60, 75, and 80 ASTM A615 [2] and A706 [3] bars, as well as Grade 335, 400, and 500 bars. Important dimensions to consider in design are sleeve length, outer and inner sleeve diameters, and elongated length after swaging, as they differ amongst the different available products. The range of sizes and grades available also differ by manufacturer. Available options for this splice include transition splicing for bars of different sizes, epoxy and galvanized coatings, and a stop component in the center of sleeve for bar positioning. Of these products, one (BarGrip XL) meets the ACI 318 and IBC Type 2 requirements, with others meeting Type 1 requirements. Three of the products (BarGrip XL, GripLock, and Bar Swage) meet the acceptance criteria established by ASME Boiler and Pressure Vessel Division 2 Code for Concrete Contaminants [10] and can thus be used in nuclear power plant concrete containment structures.

When used in nuclear power plants, cold-swaged steel couplers must meet the requirements for Fabrication and Construction (CC-4000) and Construction Testing and Examination (CC-5000) in ASME BPV CODE SECTION III/ACI 359 in addition to the ACI 318-14 criteria regulating the use of mechanical splices.

Cold-swaged steel couplers have different installation procedures, and the manufacturer must provide the following information [10]:

- Cleanliness requirements
- Type of equipment and methods used for swaging
- Required swaging pressure, method of measurement, pressure tolerance, and frequency of calibration of the hydraulic system
- Method used to verify final alignment and engagement of the coupler on both bars for splices or one bar for mechanically anchored headed deformed bars
- Bar end preparation
- Minimum and maximum number of swaging operations per sleeve and mechanically anchored headed deformed bars
- Method used to ensure sleeve and mechanical anchorage device is swaged along full length
- Limits on die wear and frequency of checking
- For sleeves that require heating, limits on and methods used to measure duration and temperature of heating cycle and temperature of sleeve at time of swaging

Continuous testing must be performed as part of QA/QC on both production splices (those installed in the field and removed for testing) and sister splices (those pulled from a production line or shipment prior to installation). Samples must be taken at the following frequencies [10]:

For production splice testing only:

- One production splice from the first 10 sleeves used.
- One production splice from next 90 sleeves used.
- Two production splices for every subsequent 100 sleeves used.

When testing with production and sister splices:

- One of each type from first 10 sleeves.
- One production and three sister splices from next 90 sleeves.
- Three of either type for each subsequent 100 sleeves used. At least one-fourth the total number of splice assemblies must be production splices.

2.1.2 Cold-swaged coupler with taper-threaded ends

One variant of the cold-swaged sleeve coupler is the cold-swaged coupler with taper threaded ends (Figure 2-2). This mechanical splice is comprised of two or more components, as opposed to the single sleeve splice described in Section 2.1.1. Each component consists of an open sleeve (in which the reinforcing bar is inserted) and a male or female taper threaded end. The sleeves are cold-swaged onto the bars using a hydraulic press and die set. The reinforcing bars require no machining but must have deformations to create mechanical interlock. The opposing sides may then be joined by the threaded ends using pipe wrenches. One of the reinforcing bars must be able to turn. If neither bar can be rotated, female threading is used for each sleeve on the reinforcing bars and a male-threaded center piece is used to join them with a locknut; this configuration is known as a position splice. This mechanical splice combines the ease of swaging the bars with the benefits of tapered connections, without a reduction in bar area. Taper-threading allows for easier connection and alignment. These splices are used for new cast-in-place construction, renovation, and repair. The splice must be inspected after installation to ensure each reinforcing bar has been fully inserted into the sleeve. Full thread engagement and alignment should also be verified.

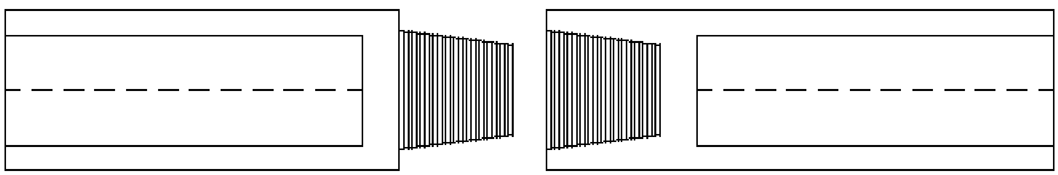

Figure 2-2
Cold-swaged steel coupler with taper-threaded ends

Three splices of this type are offered by the companies surveyed:

- GripTwist®- BarSplice Products, Inc.
- GripTwist® XL- BarSplice Products, Inc.
- KZ Hydraulic grip- KZ International

These splices are available in standard bar sizes ranging from No. 3 to No. 18 (in.-lb) and No. 10 to No. 57 (SI), with nonstandard sizes also available, and are available for Grade 60, 75, and 80 ASTM A615 [2] bars, Grade 60 and 80 ASTM A706 [3] bars, and Grade 100 and 120 ASTM A1035 bars (no SI grades were listed). Some of these splices are available as transitional couplers to allow bars of different sizes to be spliced. Positional coupler options are available for each product for cases where neither bar is free to rotate. Other options are available, such as an add-on flange for attaching to formwork. All three splices meet the requirements of a Type 1 splice in ACI 318-14 [11]; two of the splices, GripTwist and GripTwist XL, meet the requirements for a Type 2 splice. These splices also meet the criteria of AC133 [12] and ASME BPV CODE SECTION III/ACI 359 [10]; various international standards are also referenced by the companies. The KZ International coupler lists nuclear power plants among the projects in which the splice has been used.

2.1.3 Extruded steel coupler with parallel-threaded ends

A second variant of the common cold-swaged coupler is the extruded steel coupler with parallel-threaded ends (Figure 2-3). These splices are very similar in appearance and function to the cold-swaged steel coupler with taper-threaded ends (Section 2.1.2), but feature parallel-threaded ends for joining the two components. Much like the cold-swaged taper-threaded couplers, this splice is comprised of two components, each with an open sleeve and a male or female parallel-threaded end. The sleeves are cold-swaged onto the bars using a hydraulic press and die set. The reinforcing bars require no machining but must have deformations to create mechanical interlock. The two opposing ends may then be joined by connecting the threading using pipe wrenches. One of the reinforcing bars must be able to turn unless a position splice, similar to that described in Section 2.1.2, is integrated. This mechanical splice combines the ease of swaging the bars with the integrity and benefits of a threaded system. These splices are used for new cast-in-place construction, renovation, and repair. The splice must be inspected after installation to ensure each reinforcing bar has been fully inserted into the sleeve; full thread engagement and alignment should also be verified.

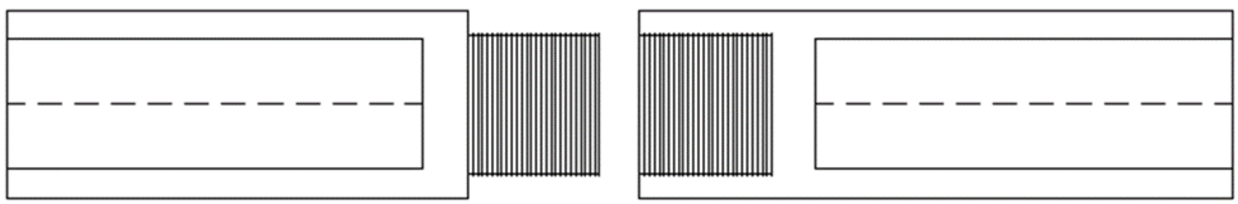

Figure 2-3
Extruded steel coupler with parallel-threaded ends

Seven splices of this type are produced by the companies surveyed:

- GripLock™- BARUS® LLC, Inc.
- Griptec- Dextra Group
- INCON ICS- INCON
- FD Grip- Fuji-Bolt Manufacturing Co., Ltd.
- C-S Joint- OCM, Inc.
- MODIX®- Peikko® Group
- KZ Hydraulic grip- KZ International

These products are available in standard sizes ranging from No. 3 to No. 18 (in.-lb) and No. 10 to No. 57 (SI). These splices are available for Grade 60 and 75 (in.-lb), Grade 420, 450, 500, and 550 (SI), and SD295A, SD295B, SD345, and SD390 (Japanese standard) bars. Many of these splices are available in transition splices (to allow bars of different sizes to be spliced), position splices (for cases when neither bar is free to rotate), and bridge splices (allowing more distance between the joined reinforcing bars). Many of the products meet the requirements of various international construction codes. For nuclear power plant application, two systems (GripLock and Griptec) meet the requirements in ASME BPV CODE SECTION III/ACI 359 [10] and CAN/CSA-N287 [42], the Canadian concrete containment code for nuclear power plants. FD Grip and KZ International list nuclear power plants among the projects in which the splice has been used.

2.2 Friction-Welded Couplers

Friction-welded couplers consist of threaded components affixed to the bar ends offsite by a fabricator. Since no machining is required on site, these splices generally require less time to install than other splice types, though they generally require manipulation (rotation) of at least one bar. Detailed information on the different types of friction-welded couplers is provided in the following sections.

2.2.1 Friction-welded bar coupler with taper-threaded ends

Friction-welded bar couplers with taper-threaded ends (Figure 2-4) consist of at least two components, with one friction-welded to each reinforcing bar. One reinforcing bar has a male taper threaded component friction welded to it, while the opposing bar has a female threaded sleeve friction-welded to it for the connection. Bars with the couplers are joined by turning one into the other. For cases where neither reinforcing bar can rotate, position splices are made using male threaded components friction-welded to the bar and a female threaded sleeve for joining. The process of friction-welding takes place offsite, but allows the use of non-deformed or irregularly deformed reinforcing bars. The mechanical splice should be checked to ensure the friction weld was performed correctly; after installation, the splice should be checked for full thread engagement.

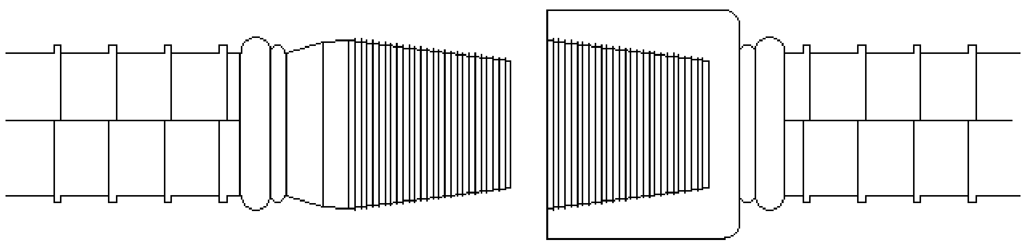

Figure 2-4
Friction-welded bar coupler with taper-threaded ends

Three friction-welded bar couplers with taper-threaded ends are produced by the companies surveyed:

- HRC® 400 series- Headed Reinforcement Corporation
- HT Coupler- HY-TEN
- KZ Friction-welding rebar coupler- KZ International

These splices are available in standard sizes from No. 5 to No. 18 (in.-lb) and No. 16 to No. 57 (SI), with nonstandard sizes also available, for ASTM A615 [2] Grade 75, ASTM A706 [3] Grade 60 and 75, and Grade 500 bars. The HT Coupler is explicitly listed as a Type 2 splice. Two of the splices (HRC 400 and HT Coupler) are available as a transition type splice. Each type is available as a positional splice for use when bars are unable to rotate. KZ International lists nuclear power plants around Taiwan among the projects in which the splice has been used.

2.2.2 Friction-welded bar coupler with parallel-threaded ends

Friction-welded bar couplers with parallel-threaded ends (Figure 2-5) are very similar in function to the friction-welded bar couplers with taper-threaded ends (Section 2.2.1). Like the friction-welded taper-threaded couplers, these couplers consist of at least two components, with one component friction-welded to the end of each reinforcing bar. An internally parallel-threaded component is attached to one bar and an externally parallel-threaded component is attached to the other. Bars with the couplers are joined by rotating them together. Installation of this type of splice involves turning at least one of the reinforcing bars. Another common configuration has externally parallel-threaded bars friction-welded to each reinforcing bar and a separate internally threaded sleeve to make the connection between the two. This configuration allows installation without rotation of either bar. The process of friction-welding takes place offsite, but allows the use of non-deformed or irregularly deformed reinforcing bars. The mechanical splice should be checked to ensure the friction weld was performed correctly; after installation, the splice should be checked for full thread engagement.

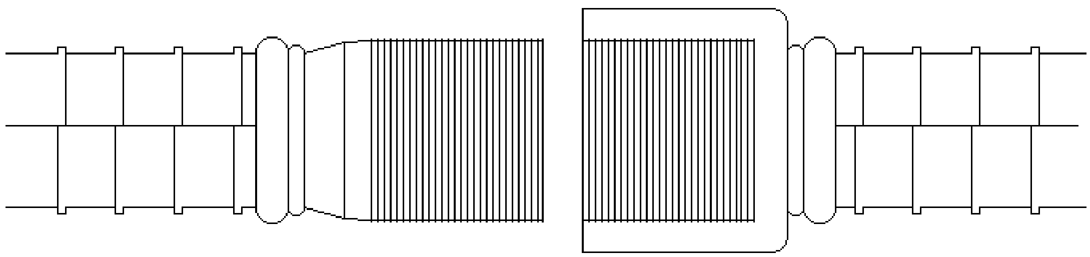

Figure 2-5
Friction-welded bar coupler with parallel-threaded ends

Four friction-welded bar couplers with parallel-threaded ends are produced by the companies surveyed:

- HRC® 400 series- Headed Reinforcement Corporation®
- HT Coupler- HY-TEN
- KZ Friction-welding rebar coupler- KZ International
- E-Splice™- NatSteel

These splices are available in standard sizes from No. 10 to No. 18 (in.-lb) and No. 16 to No. 57 (SI) for ASTM A615 [2] Grade 75, ASTM A706 [3] Grade 60 and 75, and Grade 500 bars. The E-Splice and HT Coupler are explicitly listed as Type 2 splices. Two of the splices (HRC 400 and HT Coupler) are available as transition splices. Each type is available as a positional splice for use when bars are unable to rotate. The products are compliant with the requirements of various international codes. KZ International lists nuclear power plants around Taiwan among the projects in which the splice has been used.

2.3 Screw/Wedge Sleeve Couplers

Screw/wedge sleeve couplers consist of an external clamping mechanism to achieve interlock with the bars to be spliced. Since no machining is required on site, these splices generally require less time to install than other splice types, though construction speed will vary depending on the clamping mechanism and the ease with which the splice can be accessed with tools. Detailed information on the different types of screw/wedge sleeve couplers is provided in the following sections.

2.3.1 Shear screw and rail coupling sleeve

Shear screw and rail coupling sleeves join two reinforcing bars against one another in a cylindrical steel sleeve (Figure 2-6). The sleeve has a line of shear head screws threaded into one side, while the opposing inner side has serrated rails for the reinforcing bars to bare against. The screws are tightened over one reinforcing bar at a time, embedding the bar into the serrated rails lining the sleeve. Socket wrenches or pneumatic impact wrenches are used for installation. On some versions of this splice, the heads of the screws shear off at the proper torque, allowing for rapid inspection. This splice may be used with plain or deformed bars, with no machining required. It is used in new cast-in-place construction as well as for repair and renovation. Spacing required for equipment should be taken into consideration and may require staggering the splices. The reinforcing bars should be checked for proper insertion length; some splices are available with center-stops.

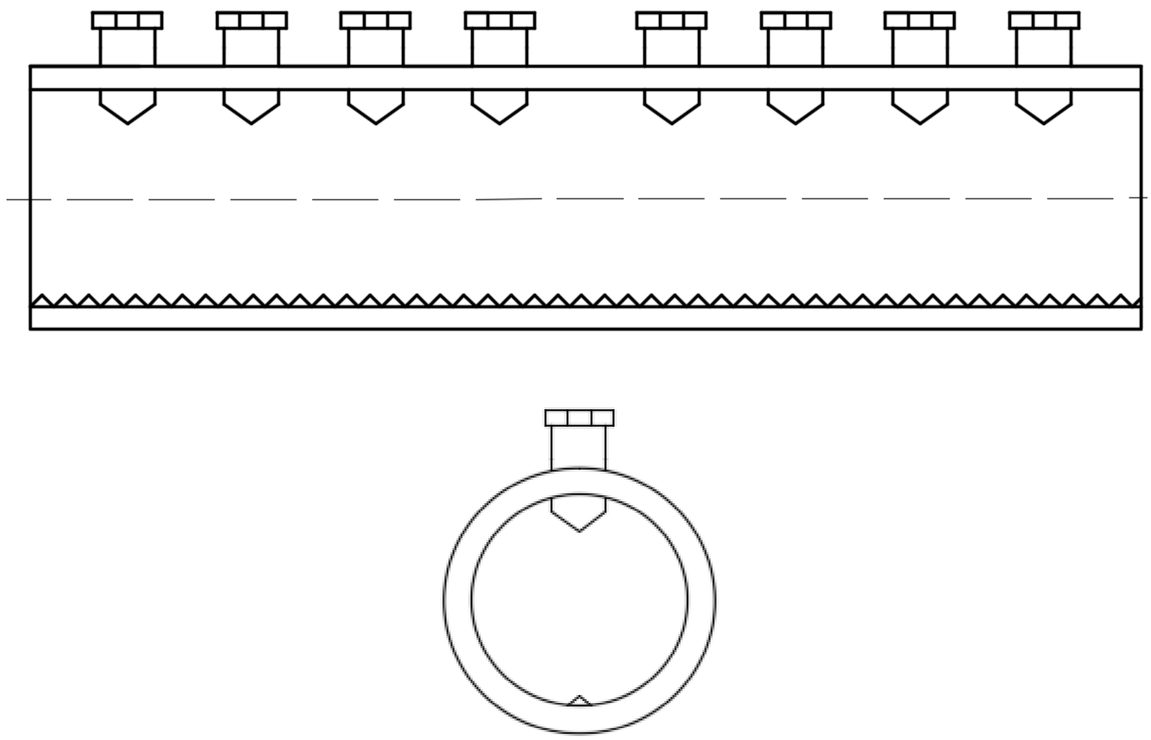

Figure 2-6
Shear screw and rail top and end view

Eight shear screw and rail coupling sleeves are produced by the companies surveyed:

- MBT Mechanically Bolted Coupler- Ancon®, Ltd.
- Jawws™ Shear Screw System- BARUS®, Ltd.
- D250L Bar Lock® coupler- Dayton Superior
- D250XL Bar Lock® coupler- Dayton Superior
- D250S/CA Bar Lock® coupler- Dayton Superior
- D630 Compression Only coupler- Dayton Superior

- Unitec- Dextra Group
- LENTON LOCK Shear Bolt Splicing System- Pentair

This splice is available in standard bar sizes from No. 3 to No. 18 (in.-lb) and No. 10 to No. 57 (SI) for ASTM A615 [2] and ASTM A706 [3] Grade 60, 75, and 80 bars; nonstandard sizes are also available. All of the products (except Jawws and D250L) satisfy ACI 318-14 Type 2 criteria [11]. Available options include transition splices, epoxy-coated splices for ASTM A775 [6] bars, and mechanically galvanized coatings [43]. One of the products (D630) is listed specifically for use in compression only. This splice has a shorter sleeve length compared to the others. Jawws, Unitec, and LENTON LOCK comply with ACI 349 [44] and ASME BPV CODE SECTION III/ACI 359 [11]; Dayton Superior lists nuclear power plants among the projects in which their splices have been used.

2.3.2 Shear screw and wedge coupling sleeve

Shear screw and wedge coupling sleeves join two reinforcing bars against one another in a steel sleeve with converging sides (Figure 2-7). The shape of the sleeve is the major difference between this splice and the shear screw and rail coupling sleeve. The sleeve has a line of shear head screws threaded into one side, while the opposing inner side has serrated rails for the reinforcing bars to bare against. The screws are tightened over one reinforcing bar at a time, embedding the bar into the serrated rails lining the sleeve. The heads of the screws shear off at the proper torque, allowing for rapid inspection. This splice may be used with deformed bars, with no machining required. It is used in new cast-in-place construction as well as for repair and renovation. Spacing required for bolt-tightening equipment should be taken into consideration and may require staggering the splices. The reinforcing bars should be checked for proper insertion length; some splices are available with center-stops.

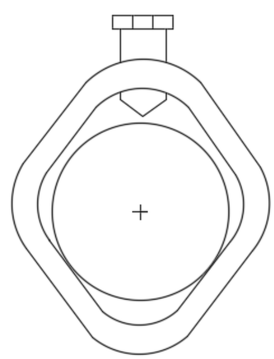

Figure 2-7
Shear screw and wedge end view

Three shear screw and wedge coupling sleeves are produced by the companies surveyed, all by one company:

- Zap Screwlok®- BarSplice Products, Inc.
- Zap Screwlok® SL- BarSplice Products, Inc.
- Zap Screwlok® FX- BarSplice Products, Inc.

This splice is available in standard sizes ranging from No. 3 to No. 18 (in.-lb) and No. 10 to No. 57 (SI) for ASTM A615 [2] and ASTM A706 [3] Grade 60, 75, and 80 and ASTM A996 [4] Grade 60 bars; one splice (Zap Screwlok FX) is available for ASTM A1035 [5] Grade 100 bars. Zap Screwlok and Zap Screwlok FX meet ACI 318-14 Type 2 criteria. Available options include transition splices and epoxy-coated splices for ASTM A775 [6] bars. All of the products are compliant with ACI 318 [11] and ICC AC133 [12]. Zap Screwlok and Zap Screwlok FX are also compliant with ASME BPV CODE SECTION III/ACI 359 [10].

2.3.3 Shear screw and double-wedge coupling sleeve

The shear screw and double-wedge coupling sleeve consists of a wide double barrel sleeve, large enough for two reinforcing bars to lay parallel on serrated rails (Figure 2-8). This mechanical lap splice uses shear head screws to lock the bars in place. The reinforcing bars rest in the sleeve on either side of a wedge holding them in place. The bars should be overlapped within the sleeve a specified length that is typically significantly shorter than required for normal lap splices. The heads of the screws shear off at the proper torque, allowing for rapid inspection. Deformed bars must be used to create interlock with the serrated rails. The system is suitable for new construction, renovation, and repair. The bars require no machining.

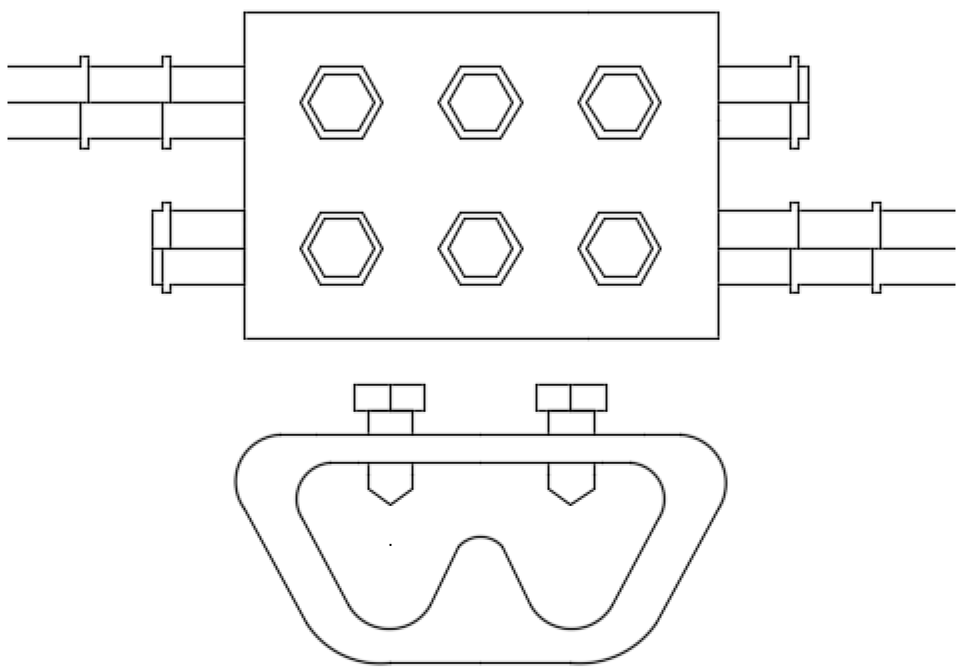

Figure 2-8
Shear screw and double-wedge coupling sleeve top and end view

Just one shear screw and double-wedge coupling sleeve is produced by the companies surveyed, the Double Barrel Zap produced by BarSplice Products, Inc. This splice is available in standard sizes ranging from No. 3 to No. 8 (in.-lb) and No. 10 to No. 25 (SI) for ASTM A615 [2] Grade 60 bars. This is a Type 1 splice and is available with ASTM A775 [6] epoxy and ASTM A767 [8] hot-dipped galvanized coating. Transition splices are also available.

2.3.4 Steel coupling sleeve with wedge

The steel coupling sleeve with wedge consists of a wide double barrel sleeve large enough for two reinforcing bars to lay parallel (Figure 2-9). This mechanical lap splice uses a hydraulically driven wedge to lock the bars in place. The bars are overlapped a specified length that is shorter than used for a normal lap splice. A handheld hydraulic pump or similar device is used to drive the wedge in place. Deformed bars must be used to create interlock. It is suitable for new construction, renovation, and repair. No bar machining is necessary.

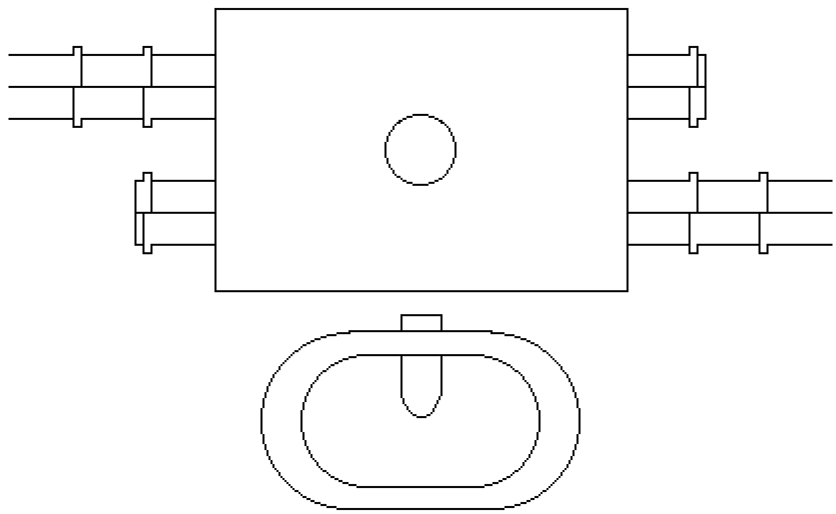

Figure 2-9
Steel coupling sleeve with wedge

One shear screw and double-wedge coupling sleeve is produced by the companies surveyed, the LENTON QUICK WEDGE mechanical lap splicing system from Pentair. The splice is available in standard sizes ranging from No. 4 to No. 6 (in.-lb) for Grade 60 bars (SI sizes are not currently produced). This is a Type 1 splice and is available with ASTM A775 [6] epoxy and ASTM A767 [8] hot-dipped galvanized coating.

2.3.5 Strap-type steel coupling sleeve

The strap-type steel coupling sleeve (Figure 2-10) is intended for use in compression only. It is comprised of a half-cylindrical steel sleeve with a flange on one side and slots on the other side. Straps fit through those slots and bolt to the flange to hold two opposing bars. The bars for this mechanical splice must be deformed, saw cut bars (other cutting methods that produce a flat end may also be used), although the splice is capable of compensating for some unevenness in the ends of the bars. Installation starts with inserting one bar halfway into the sleeve and tightening the bolts adjacent to that bar. The second bar is butted against the first bar and the rest of the bolts are tightened. The bolts typically require only 14-20 ft-lb (19-27 N-m) of torque and may be hand tightened with a ratchet wrench; power wrenches or similar devices may quicken the process. The bars do not need to be machined, the splice can be installed without significant manipulation of the bar, and the splice is able to be removed and used elsewhere after initial placement. The splice may be used in new cast-in-place construction and for repair and renovation. The splice must be inspected after installation to ensure the bolts have been tightened; given the low required torque, this is typically done via visual inspection or by verifying the bars cannot move independently of each other.

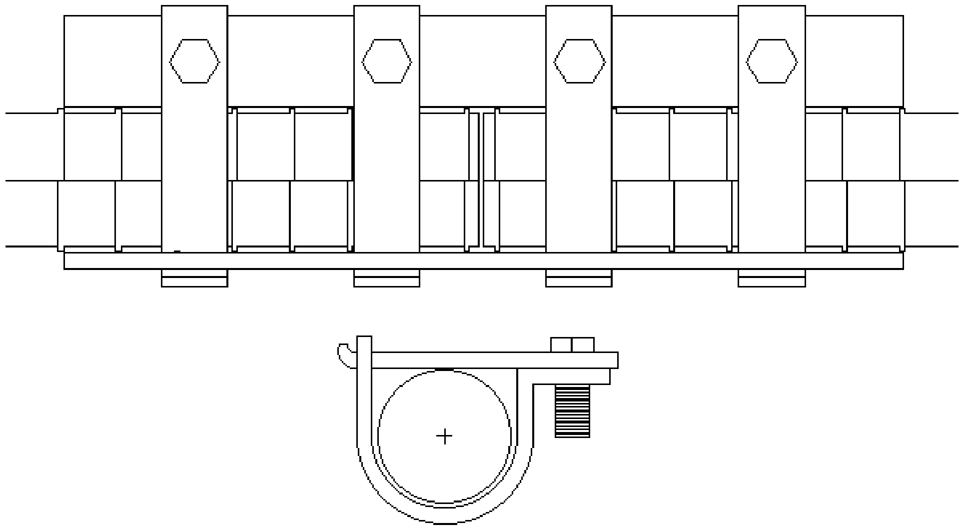

Figure 2-10
Strap-type steel coupling sleeve side view (top) and end view (bottom). For compressive forces only

Compression splices are very limited internationally, with only one strap-type steel coupler identified in the survey:

- Lenton® Speed Sleeve- Pentair

The coupler has an electrogalvanized finish and is available for use with standard bar sizes from No. 6 to No. 18 (in.-lb) and No. 20 to No. 57 (SI). (No information on steel grade was provided by the producer.) Transitioning from one bar size to another is done with an adapter insertion. The bar ends must be cut to an angle within 1.5 degrees of perpendicular to the axis of the bar and must be fitted to within 3 degrees of full bearing; readjustment may be necessary during installation.

2.4 Threaded Couplers

Threaded couplers consist of threads machined into the ends of reinforcing bars to be spliced, a task generally performed offsite by a fabricator. Since no machining is required onsite, these splices generally require less time to install than other splice types, though they generally require manipulation (rotation) of at least one bar. Detailed information on the different types of threaded couplers is provided in the following sections.

2.4.1 Integrally forged coupler with flange

Integrally forged couplers with flanges (Figure 2-11) are manufactured using only the steel reinforcing bars. One bar is hot-forged with a flange and threaded internally. The other reinforcing bar is hot forged to increase the cross-sectional area and machined with external threading. This threading matches the internal threads on the forged end of the other reinforcing bar without resulting in a reduction in nominal bar area. At least one reinforcing bar must be able to rotate. This splice is used for new cast-in-place construction only, and bars must be machined offsite. The threading is shielded until ready for installation. After installation, the threading should be checked for full engagement.

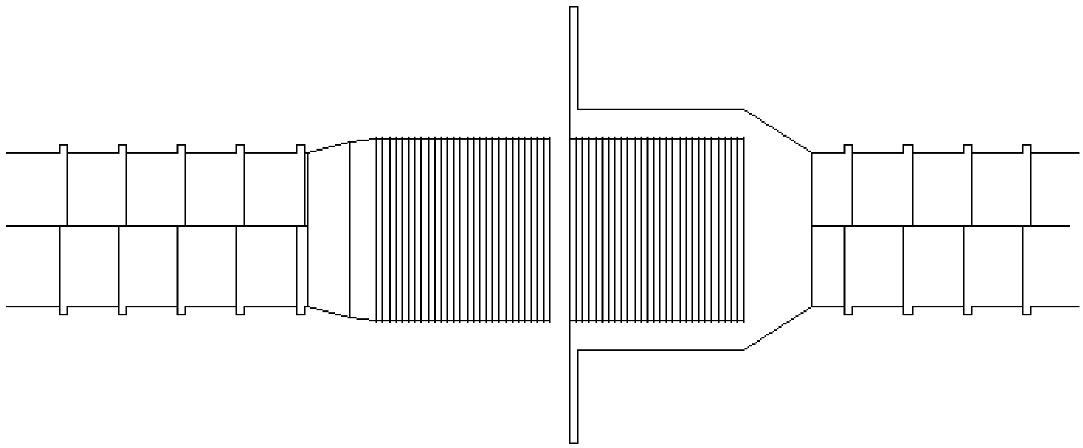

Figure 2-11
Integrally forged coupler with flange

Two integrally forged couplers are produced by the companies surveyed, both by the same company:

- D50 DBR™ coupler system- Dayton Superior
- DBDI™ splice system- Dayton Superior

These splices are available for use with standard bar sizes from No. 4 to No. 11 (in.-lb) and No. 13 to No. 36 (SI). Both products meet ACI 318 [11] Type 2 criteria for Grade 60 bars. The splices are integral with the bars; these bars are available in straight lengths or hooked 90° or 180° at the non-spliced end. There are double-ended dowel bars with sleeves on each end available, but no transition or position splices.

2.4.2 Taper-threaded steel coupler

Taper-threaded couplers (Figure 2-12) are composed of a steel sleeve internally threaded on each side to fit taper-threaded reinforcing bars. The machined bars are rotated into the sleeve by hand, with a pipe wrench, or in a similar manner. If neither of the bars can be rotated, an alternate threading pattern that allows for both bars to be tightened by rotation of the sleeve may be used. Tapered threading is known to reduce field damage or cross threading (damage caused by tightening with misaligned threads), along with aiding in bar alignment. This splice is typically used for new construction because reinforcing bars are typically machined offsite (or, for some splices, proprietary bars are required). The threading is shielded until ready for installation.

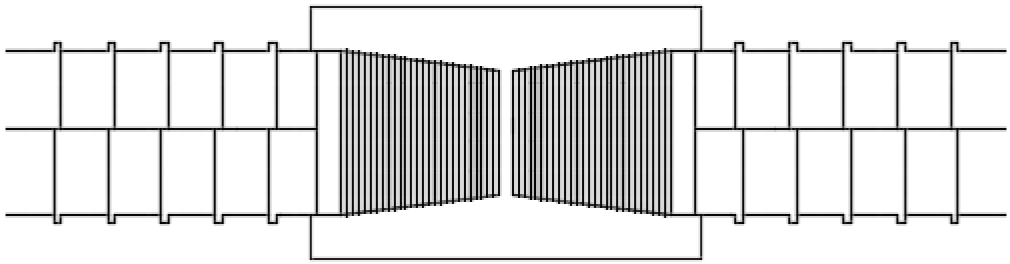

Figure 2-12
Taper-threaded steel coupler

Eight taper-threaded steel couplers are produced by the companies surveyed for this study:

- Ancon taper-thread couplers- Ancon®, Ltd.
- Ancon cryogenic couplers- Ancon®, Ltd.
- BARUS TTEX™ System- BARUS®, LLC. Inc.
- D310 Taper-Lock® standard coupler- Dayton Superior®
- Moment® Spearline- Halfen-Moment® Inc.
- KZ threaded rebar coupler- KZ International
- Lenton taper-threaded splicing systems- Pentair
- Taper-threaded couplers- Spplicetek™ India Pvt. Ltd.

This splice is available in standard sizes from No. 3 to No. 18 (in.-lb) and No. 10 to No. 57 (SI) for ASTM A615 [2] Grade 60, 75, and 80, ASTM A706 [3] Grade 60 and 80, ASTM A1035 [5] Grade 100 and 120, and Grade 420, 500, and 550 (SI) bars. D310 Taper-Lock, Moment Spearline, Lenton Taper, and Spplicetek splices meet ACI 318-14 [11] Type 2 criteria. Positional couplers for non-rotating bars and transitional couplers are available among the products. The splices are available for coated bars – mechanically galvanized [43], hot-dip galvanized [8], electrogalvanized [45], and epoxy-coated [6]. Other options include bridging splices to close gaps between bars, flanges for mounting to formwork, stainless steel, cryogenic, and couplers listed specifically for use in nuclear power plants. The BARUS TTEX and Lenton taper-threaded systems comply with ASME BPV CODE SECTION III/ACI 359 [10]; KZ International and Dayton Superior list nuclear power plants among the projects in which their splices have been used.

When used in nuclear power plants, taper-threaded steel couplers must meet requirements in ASME BPV CODE SECTION III/ACI 359 [10] in addition to the ACI 318-14 [11] criteria for mechanical splices. CC-4000 covers the testing frequency, requirements, and installation requirements. ASME BPV CODE SECTION III/ACI 359 also requires that detailed installation instructions be provided by the manufacturer. These instructions must include [10]:

- Cleanliness requirements
- Type of equipment and methods used to verify bar thread acceptability
- Type of equipment and methods used for torqueing

- Required tightening torque and method of measurement
- Method of mechanically locking the position splices
- Method used to verify the final alignment and engagement of the coupler on both bars for splices

The taper-threaded splice must also meet requirements in the Construction Testing and Examination article (CC-5000) from ASME BPV CODE SECTION III/ACI 359 [10].

- Bar ends and splice sleeves must be visually examined prior to assembly for cleanliness.
- Threads must be checked with a manufacturer's thread gage.
- Bars must be marked with a suitable marker to indicate depth of insertion into splice. After assembly, the actual depth of insertion must be checked for compliance with CC-4333.3 by means of this mark.
- Proper assembly and torque must be checked for compliance with the installation procedure described in the construction specification.
- One splice for each 100 production splices must be disassembled and inspected for compliance with CC-4333.3, and all threads rechecked with the manufacturer's thread gage.

2.4.3 Parallel-threaded steel coupler

The parallel-threaded steel coupler (Figure 2-13) is comprised of a sleeve with internal parallel threading. The reinforcing bars are machined with parallel threading or have threading rolled in; some splices are designed for use with proprietary threaded bars. A pipe wrench or similar tool may be used for installation. This splice is used for new cast-in-place construction only, and bars may be machined on or offsite. The threading is shielded until ready for installation. The threading should be checked for full engagement and proper length. Center stops or control of the threading length ensures proper insertion length.

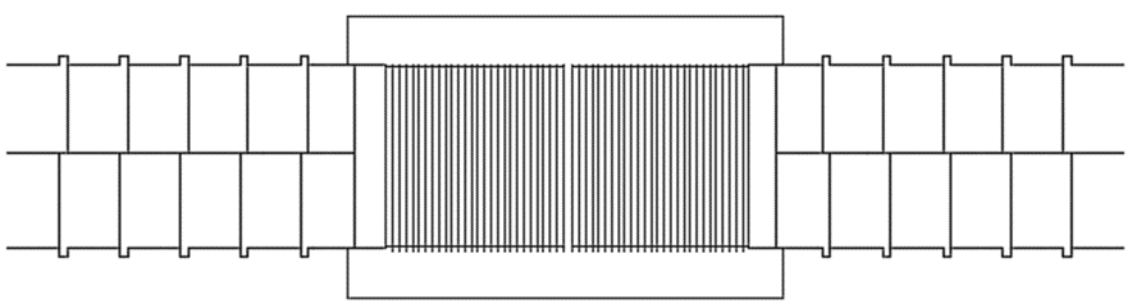

Figure 2-13
Parallel-threaded steel coupler

Seven different parallel-threaded steel couplers are produced by the companies surveyed for this study:

- Rolltec- Dextra Group
- Moment® JointTec- Halfen-Moment® Inc.

- Moment® Rebartech coupler- Halfen-Moment® Inc.
- KZ Threaded rebar coupler- KZ International
- Parallel thread rebar coupler- OCEPO®
- ReidBar™ couplers- ReidBar™
- Parallel threaded steel coupler- Yau Lee Metals and Building Materials Co., Ltd.

No suppliers in the United States produce this type of splice; as such, the splice is only available in SI sizes. This splice is available in sizes from No. 12 to No. 50 (SI) for Grade 335, 400, 420, 500, and 550 steel. Splices are available that meet both Type 1 and 2 requirements in ACI 318-14 [11]. No positional splices are available; therefore, at least one reinforcing bar must be able to turn. Transition splices are available. Rolltec and the Halfen-Moment splices comply with ASME BPV CODE SECTION III/ACI 359 [10] and CAN/CSA-N287 [42], respectively.

2.4.4 Threaded coupler with standard national coarse threads

This threaded coupler is comprised of a sleeve internally threaded with standard national coarse threads (Figure 2-14). The reinforcing bars are machined to obtain the threading; no forging is necessary. The reinforcing bars lose up to 25% of their area when machined with standard coarse threads. If neither of the bars can be rotated, a positional coupler may be used. Positional couplers for this and other threaded bar systems involves threading one of the bars to a length greater than the length of the coupling sleeve; this allows the coupler and a locknut to be fully threaded on the bar. When the second bar is placed, the coupling sleeve is partially unthreaded from the first bar while threading to the second bar. Once the sleeve is threaded on the second bar to the proper depth, the locknut is tightened against the sleeve to prevent rotation (Figure 2-15). This splice is used for new cast-in-place construction only, because reinforcing bars are typically machined offsite or are proprietary. The threading is shielded until ready for installation. The threading should be checked for full engagement and proper length. Center stops or control of the threaded length ensures proper length.

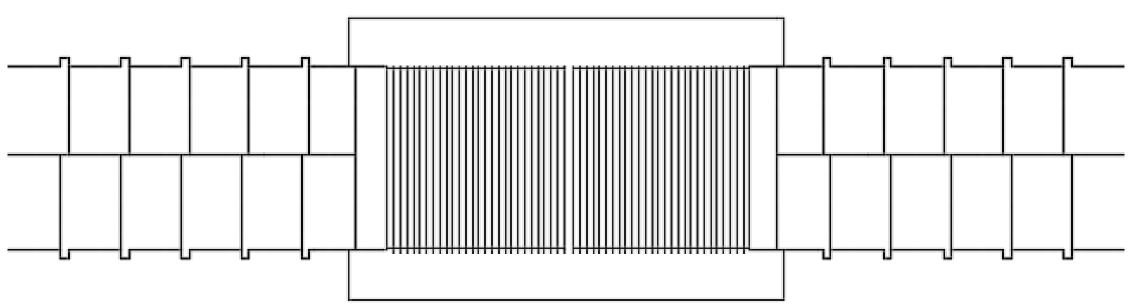

Figure 2-14
Threaded coupler with standard national coarse threads

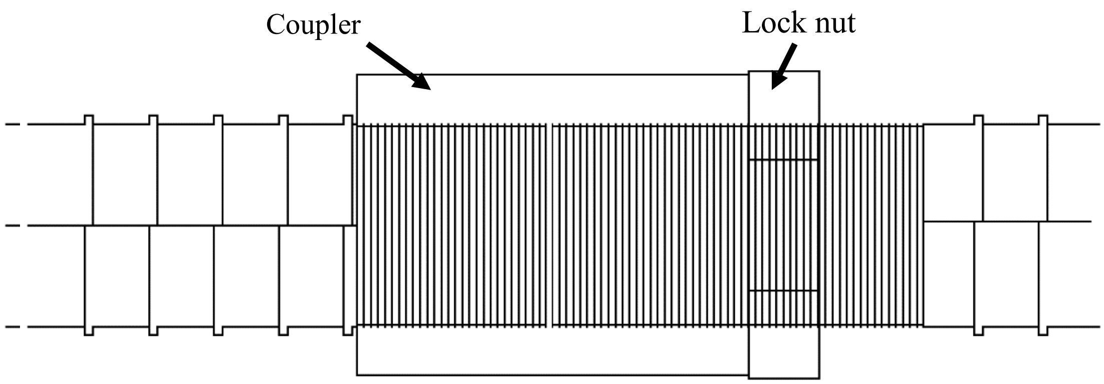

Figure 2-15
Threaded coupler with position splice

Six couplers with standard coarse national threads are produced by the companies surveyed for this study:

- BPI® BarSplicer- BarSplice Products, Inc.
- BPI® Stainless BarSplicer- BarSplice Products, Inc.
- BPI® 100 ksi BarSplicer- BarSplice Products, Inc.
- GEWI® threadbar system- DYWIDAG Systems International
- HRC® 300 series- Headed Reinforcement Corp®.
- RC-53 threaded rebar couple smooth- MeadowBurke®

This splice is available in standard sizes ranging from No. 4 to No. 11 (in.-lb) and No. 13 to No. 43 (SI) for ASTM A615 [2] Grade 60 and 75, ASTM A706 [3] Grade 60, 75, and 80, and ASTM A1035 [5] Grade 100 bars, as well as SI Grade 500, 670, and 800 bars. Nonstandard sizes are also available. With the exception of the BPI Stainless BarSplicer and RC-53 couplers, all of the products meet ACI 318-14 Type 2 [11] criteria. Positional couplers for non-rotating bars are available for some products, but no transition splices are available. Additional options include flanges for mounting to formwork and corrosion resistant stainless steel couplers.

For use in nuclear power plants, standard national coarse threaded steel couplers must meet the requirements for couplers with threaded sleeves in ASME BPV CODE SECTION III/ACI 359 in addition to the ACI 318-14 criteria for mechanical splices. Testing frequency, requirements, and installation requirements exist for the coupler in CC-4000.

ASME BPV CODE SECTION III/ACI 359 also requires that detailed installation instructions be provided by the manufacturer for all threaded splices. These instructions must include [10]:

- Cleanliness requirements
- Type of equipment and methods used to verify bar thread acceptability
- Type of equipment and methods used for torqueing
- Required torque, tolerance on required torque, and method of measurement

- Method used to lock the coupling in position to prevent loosening of the splice
- Method used to verify the final alignment and engagement of the coupler on both bars for splices

The standard national coarse threaded splices must also meet requirements in the Construction Testing and Examination article (CC-5000) from ASME BPV CODE SECTION III/ACI 359 [10].

- Bar ends and splice sleeves must be visually examined prior to assembly for damage, cleanliness, and proper end preparation.
- Threads must be checked with a manufacturer's thread gage.
- Bars must be marked with a suitable marker to indicate depth of insertion into splice. After assembly, the actual depth of insertion must be checked for compliance with CC-4333.3 by means of this mark.
- Proper assembly and torque must be checked for compliance with the installation procedure described in the construction specification.
- One splice for each 100 production splices must be disassembled and inspected for compliance with CC-4333.3, and all threads rechecked with the manufacturer's thread gage.

2.4.5 Threaded coupler with upsized bar threads, cold-forged

This mechanical splice is comprised of a sleeve with internal parallel threading (Figure 2-16). The ends of the reinforcing bars are upsized with cold-forged steel, then the parallel threading is machined to match the bar size. This prevents the loss of bar area that typically occurs when threading a reinforcing bar. Prior to machining, the bars should be square cut. If neither of the bars can be rotated, a positional coupler (similar to that shown in Figure 2-15) may be used. This splice is used for new cast-in-place construction only because the reinforcing bars are typically machined offsite or are proprietary. The threading is shielded until ready for installation. After installation, the threading should be checked for full engagement and proper length. Center stops or control of the threading length ensures proper engagement.

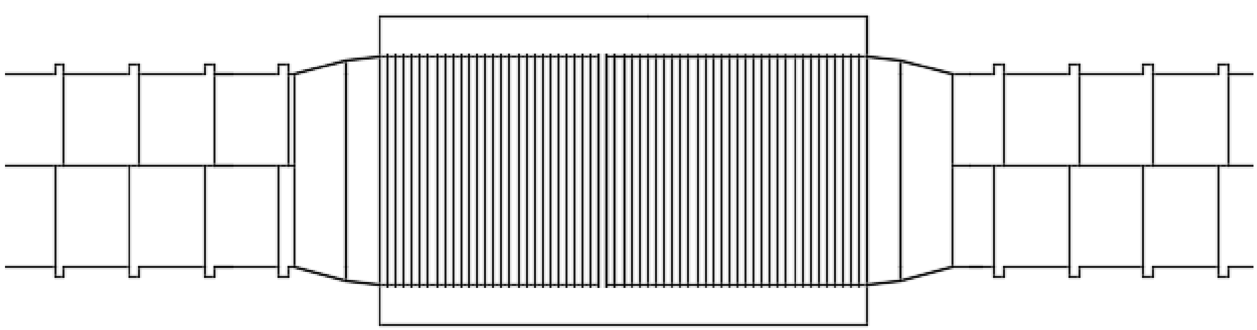

Figure 2-16
Threaded coupler with upsized bar threads, cold-forged

This splice is the most commonly available system among the companies surveyed. Sixteen different upsized cold-forged bar threaded couplers are produced by the companies surveyed:

- BT Stainless steel coupler- Ancon®, Ltd.
- Bartec Plus- Ancon®, Ltd.
- Bartec- Ancon®, Ltd.
- CXL couplers- Ancon®, Ltd.
- Hérisson®- Armaturis®
- Hérisson® + Mono- Armaturis®
- Firsty®- Armaturis®
- SimGrip™- BARUS® LLC., Inc.
- Threaded Barlink SBT Coupler- Best Notch Group
- Bartec- Dextra Group
- Fortec- Dextra Group
- MECH-JOINT- Hi-Tech
- INCON IBS- INCON
- Upset forging rebar coupler- OCEPO®
- ‘IRON MAN’ BMS- Preshcon Industries PTE. Ltd.
- Cold forged parallel thread couplers (CFPT)- Spplicetek™ India Pvt. Ltd.

This splice is available in standard sizes from No. 4 to No. 18 (in.-lb) and No. 13 to No. 43 (SI) for ASTM A615 [2] Grade 60, 75, and 80 (in.-lb), ASTM A1035 [5] Grade 100 (in.-lb), and Grade 335, 420, 500, 550, 670, and 800 (SI) bars; nonstandard sizes are also available. Both Type 1 and 2 splices [11] are available. Positional couplers for non-rotating bars and transitional sizes are available among the products. Additional options include flanges for mounting to formwork, stainless steel splices, and bridging splices. The Bartec (Ancon), SimGrip, Bartec (Dextra), Fortec, and Spplicetek couplers comply with ASME BPV CODE SECTION III/ACI 359 [10] and CAN/CSA N287 [42].

For use in nuclear power plants, cold-forged parallel-threaded splices must meet specific requirements in ASME BPV CODE SECTION III/ACI 359 [10] in addition to the ACI 318-14 [11] criteria for mechanical splices. Testing frequency and installation requirements for the coupler are described in CC-4000 of ASME BPV CODE SECTION III/ACI 359. ASME BPV CODE SECTION III/ACI 359 also requires that detailed installation instructions be provided by the manufacturer for all threaded splices. These instructions must include [10]:

- Cleanliness requirements
- Type of equipment and methods used to verify bar thread acceptability
- Type of equipment and methods used for torqueing

- Required torque, tolerance on required torque, and method of measurement
- Method used to lock the coupling in position to prevent loosening of the splice
- Method used to verify the final alignment and engagement of the coupler on both bars for splices

The cold-forged parallel threaded splices must also meet requirements in the Construction Testing and Examination article (CC-5000) from ASME BPV CODE SECTION III/ACI 359 [10].

- Bar ends and splice sleeves must be visually examined prior to assembly for cleanliness.
- Threads must be checked with a manufacturer's thread gage.
- Bars must be marked with a suitable marker to indicate depth of insertion into splice. After assembly, the actual depth of insertion must be checked for compliance with CC-4333.3 by means of this mark.
- Proper assembly and torque must be checked for compliance with the installation procedure described in the construction specification.
- One splice for each 100 production splices must be disassembled and inspected for compliance with CC-4333.3, and all threads rechecked with the Manufacturer's thread gage.

2.4.6 Coupler for thread-like deformed reinforcing bars

Couplers for thread-like deformed reinforcing bars are made using proprietary bars with thread-like deformations able to join through a threaded sleeve (Figure 2-17). The thread-like deformations allow some couplers to be placed without requiring rotation of the bars. The finished assembly should be checked for proper thread engagement and alignment. The reinforcing bars should be checked for proper embedment length in the sleeve. Some couplers are equipped with a center stop for verification.

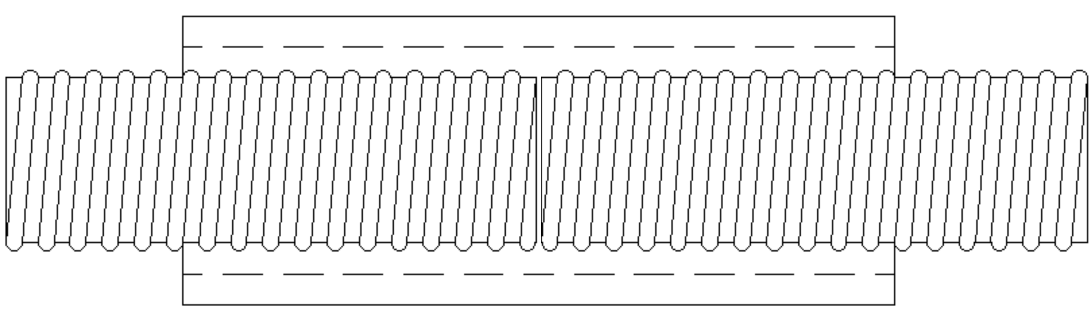

Figure 2-17
Coupler for thread-like deformed reinforcing bars

Three coupling sleeves for thread-like deformed reinforcing bars are produced by the companies surveyed:

- SAS 500/550 Reinforcing thread bar coupling system- SAS Stressteel, Inc.
- Threaded bar and accessories- Skyline Steel
- Threaded bar with fasteners- Williams Form Engineering Corp.®

The threaded bars and splices are available in sizes ranging from No. 4 to No. 28 (in.-lb) and No. 13 to No. 57 (SI); nonstandard sizes are also available. Bars and splices are available in ASTM A615 [2] Grade 60, 75, and 90, ASTM A722 [46] Grade 150, Grade 97, and SI Grade 500, 550, and 670. Both Type 1 and 2 splices are available. Since the reinforcing bars are proprietary, they are available in sizes and strengths not found in ordinary reinforcing steel, but the products are not cross-compatible with products from other companies or with standard reinforcing bars. These products are available with cold- or hot-rolled bars and hot-dipped galvanized coupler-bar combinations.

2.4.7 Upset bar and coupling sleeve with straight threads

Upset bars and coupling sleeves with straight ends are installed by slipping an internally threaded sleeve over one reinforcing bar and an externally threaded sleeve over the other. These sleeves fit loosely over the bar, and are free to rotate. The ends of the reinforcing bars are then pressed hydraulically (upset) onsite or offsite, compressing and expanding the bar ends. The sleeves are designed to partially slide over the upset ends while remaining free to rotate; caps or other end bearing at the far end of each sleeve prevent the sleeve from being fully removed from the bar once the ends are upset (Figure 2-18). Using a torque wrench, or similar device, the threaded components may be joined over the upset bars without the need for turning the reinforcing bars. Shim plates can be used to fill any space between upset ends. The threading is shielded until ready for installation. The threading should be checked for full engagement after installation.

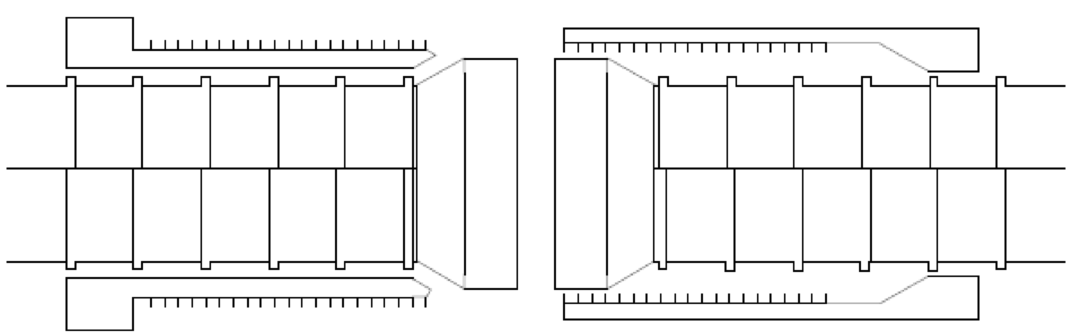

Figure 2-18
Upset bar and coupling sleeve with straight threads

Two upset bar and coupling sleeves with straight threads are produced by one of the companies surveyed for this study:

- HRC® 500 XL/510 XL series- Headed Reinforcement Corp.®
- HRC® 520/525 form protector- Headed Reinforcement Corp.®

These splices are available in standard sizes from No. 4 to No. 14 (in.-lb) for ASTM A615 [2] and ASTM A706 [3] Grade 60 bars as a Type 2 splice. Transition of up to two bar sizes is available. No compliances with ASME BPV CODE SECTION III/ACI 359 [10] are listed.

2.5 Filled Couplers

Filled couplers consist of a hollow tube placed around the bar and filled with a binder material. Although no machining is required on site, the binder material generally requires some time to gain strength. Thus, while quick to install, these types of splices generally must be left undisturbed for some time to achieve interlock. Detailed information on the different types of friction-welded couplers is provided in the following sections.

2.5.1 Grout-filled coupling sleeve

Grout-filled coupling sleeves (Figure 2-19) consist of a broad steel or ductile iron sleeve with inner deformations resembling reinforcing bars and inlet and outlet holes that allow for the addition of grout. Reinforcing bars are inserted into each end, meeting at the center. Grout is then poured or pumped into the sleeve through the sleeve inlet until grout flows from the outlet hole. When installation is complete, the system must not be moved until the grout has reached a specified minimum compressive strength. The sleeves are typically capped or “choked” on one side to prevent pullout after hardening. Options include a center stop to help with proper bar insertion. This splice must be used with deformed bars to create mechanical interlock with the grout. The use of grout does allow minor misalignments in the bar placement. Grout-filled splices can be used with bars oriented horizontally, vertically, or diagonally. When the inlet and outlet holes are at different elevations, the inlet hole must be positioned as the lower hole to ensure proper filling. The splice should be inspected to ensure proper filling and interlock within the sleeve; typically, this is done by visual inspection for grout at the outlet hole and sleeve ends. This type of sleeve has a larger outside diameter than most threaded sleeves; therefore, spacing in the member is an important consideration.

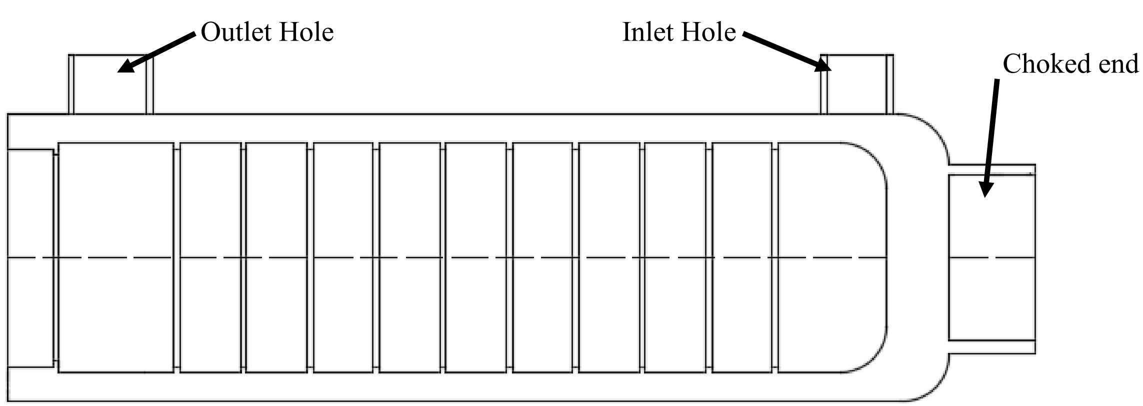

Figure 2-19
Grout-filled coupling sleeve

Four grout-filled coupling sleeves are produced by the companies surveyed for this study:

- D410 Sleeve-Lock®- Dayton Superior
- M-Type- Fujibolt Manufacturing Co., Ltd.
- ReidBar™ Grouters- ReidBar
- NMB Splice-Sleeve- Splice Sleeve

These products are available in standard sizes ranging from No. 4 to No. 18 (in.-lb) and No. 13 to No. 57 (SI), with nonstandard sizes also available, for ASTM A615 [2] and A706 [3] Grade 60, and SI Grade 500 bars. All but the Fujibolt M-Type meet the requirements in ACI 318-14 [11] for Type 2 splices. Positional splices are unnecessary for this system, and none of the products have transition splices. The products use proprietary grouts.

For use in nuclear power plants, grout-filled steel couplers must meet requirements in ASME BPV CODE SECTION III/ACI 359 [10] in addition to the ACI 318-14 criteria for mechanical splices. In CC-4000, testing frequency and installation requirements are specified for the coupler. General grout criteria for this section states that the location of all inlets and outlets for grout injection be identified in the construction plans.

ASME BPV CODE SECTION III/ACI 359 also requires that detailed installation instructions be provided by the manufacturer for all grout-filled splices. These instructions must include [10]:

- Cleanliness requirements
- Bar end preparation
- Bar end location tolerances
- Bar and sleeve centering requirements
- Permissible gap between reinforcing bar ends
- Allowable voids (gaps or large air bubbles) in grout
- Procedures for storing, mixing, placing, and curing the grout
- Maximum and minimum temperatures of the splice system during placement and curing of grout

AC133 [12] identifies tests and criteria specific to grout-filled splices. The grout must be tested to determine the minimum compressive strength required to achieve adequate interlock with the bar; the grout must also demonstrate adequate freeze-thaw resistance. Grout-filled splices must be evaluated for tensile strength using bars with at least three different deformation patterns to ensure adequate interlock.

2.5.2 Grout-filled coupling sleeve with taper-threaded ends

Grout-filled coupling sleeves with taper-threaded ends are comprised of a broad steel or ductile iron sleeve with inner deformations resembling reinforcing bars and inlet and outlet holes for the grout (Figure 2-20). This splice is similar in function to a standard grout-filled coupling sleeve (Section 2.5.1), but uses a taper-threaded connection to achieve interlock with one of the bars to be spliced. This splice, therefore, requires machining of one of the bars to be spliced. The other side of this sleeve resembles a grout-filled sleeve; the bar inserted into the sleeve is encased in grout and requires no machining. The taper-threaded bar is rotated into place, then the other bar is inserted into the open end and grout is poured or hand-pumped into the sleeve through the outfitted inlet. When installation is complete, the system must not be moved until the grout has reached a minimum compressive strength, specified by the manufacturer. The advantages, limitations, and code requirements for this splice are otherwise identical to those outlined for the grout-filled coupling sleeve in Section 2.5.1.

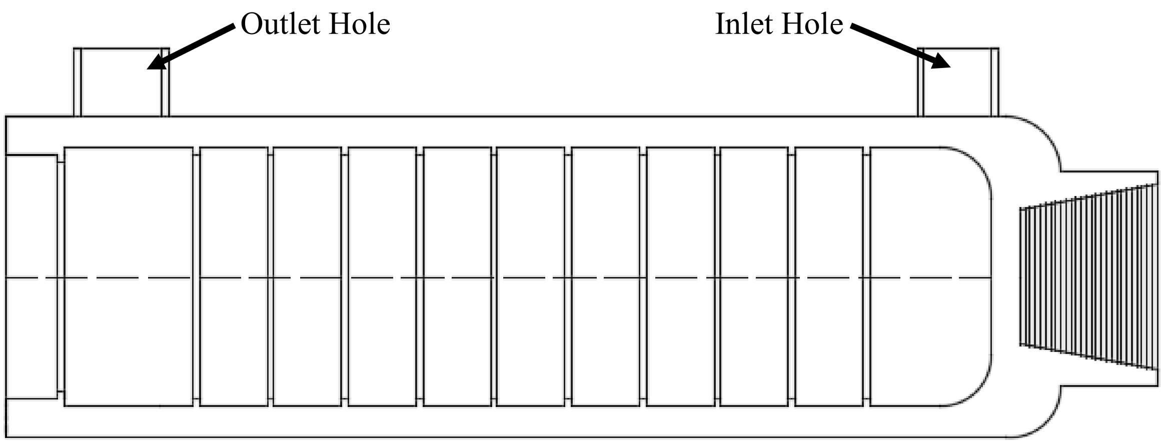

Figure 2-20
Grout-filled coupling sleeve with taper-threaded ends

Two grout-filled coupling sleeves with taper-threaded ends are produced by the companies surveyed for this study:

- Ancon grout sleeve coupler- Ancon Ltd.
- LENTON INTERLOCK Grout-Fill- Pentair

This splice is available in standard sizes from No. 5 to No. 18 (in.-lb) and No. 16 to No. 57 (SI) and is suitable for bars up to Grade 550. Transition splices are available. LENTON INTERLOCK meets the ACI 318-14 [11] requirements for a Type 2 splice and meets the requirements for use in nuclear power plants under ACI 349 [44], ASME BPV CODE SECTION III/ACI 359 [10], and CAN/CSA – N287 [42].

2.5.3 Grout-filled coupling sleeve with parallel-threaded ends

Grout-filled coupling sleeves with parallel-threaded ends (Figure 2-21) are comprised of a broad steel or ductile iron sleeve with inner deformations resembling reinforcing bars and inlet and outlet holes for the grout. This splice is similar in function to a standard group-filled coupling sleeve (Section 2.5.1) and grout-filled coupling sleeve with taper-threaded ends (Section 2.5.2), but uses a parallel-threaded connection to achieve interlock with one of the bars to be spliced. This splice, therefore, requires machining of one of the bars to be spliced. The other side of this sleeve resembles a grout-filled sleeve. The bar inserted into the sleeve is encased in grout and requires no machining. The parallel-threaded bar is rotated into place and the grout is poured or hand-pumped into the sleeve through the inlets. The advantages, limitations, and code requirements for this splice are otherwise identical to those outlined in Section 2.5.1.

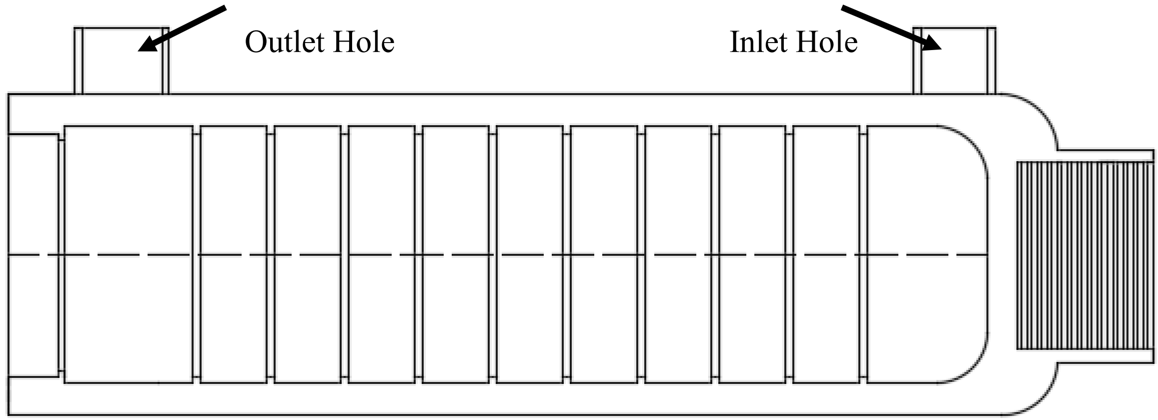

Figure 2-21
Grout-filled coupling sleeve with parallel-threaded ends

One splice of this type is produced by the companies surveyed for this study:

- Groutec- Dextra Group.

This product is available in standard sizes from No. 13 to No. 36 (SI), and SI Grade 420, 500, and 550 (not specified for in.-lb sizes or grades). Nonstandard sizes are also available. No transition splices or coatings are available. The system meets the ACI 318-14 [11] requirements for a Type 1 splice.

2.5.4 Steel-filled coupling sleeve

Steel-filled coupling sleeves consist of a broad steel or ductile iron sleeve with inner deformations resembling a reinforcing bar. They are similar to the sleeves used for grout-filled splices (Figure 2-19), with inlet and outlet holes, but are designed to withstand the higher temperatures associated with the molten steel filler. Reinforcing bars are inserted into each side, meeting at the center. Molten steel is then poured into the sleeve through the inlet. There are options for a center stop to help with proper bar insertion. Deformed bars must be used to create a mechanical interlock with the hardened steel. This splice does allow minor misalignments in the bar placement. After installation, the ends of the splice should be inspected to ensure the filler material is visible (thus ensuring the splice has been filled). This type of sleeve has a larger outside diameter than most threaded sleeves; therefore, spacing is an important consideration.

One splice of this type is produced by the companies surveyed for this study:

- LENTON CADWELD- Pentair

This splice is available in standard sizes from No. 5 to No. 18 (in.-lb) and No. 16 to No. 57 (SI) for use with all grades of steel. The splice has different models for filling horizontally and vertically oriented bars. The system meets the ACI 318-14 [11] requirements for a Type 2 splice. Options include extended length sleeves and transition splices. The splice is intended for use with proprietary steel ferrous filler material that must be poured in situ. The splice is compliant with ACI 349 [44], ASME BPV CODE SECTION III/ACI 359 [10], and CAN/CSA – N287 [42], among others, and lists multiple nuclear power plants where the splice has been used. In addition to the criteria for mechanical splices, steel-filled steel couplers must also meet requirements in ASME BPV CODE SECTION III/ACI 359 for use in nuclear power plants. In CC-4000, testing frequency and installation requirements are specified for the coupler. ASME BPV CODE SECTION III/ACI 359 also requires that detailed installation instructions be provided by the manufacturer for all steel-filled splices. These instructions must include [10]:

- Cleanliness requirements
- Bar end preparation
- Bar end location tolerances
- Permissible gaps between the reinforcing bar ends for splices
- Allowable voids (gaps or air bubbles) in filler metal

The steel-filled splice must also meet requirements in the Construction Testing and Examination article (CC-5000) of ASME BPV CODE SECTION III/ACI 359 [10]:

- One sleeved connection from each day's work per splicing crew must be examined daily for proper fit-up
- All completed sleeved connections must be visually examined after cooling for acceptable bar end locations. Filler metal must be visible at accessible ends of the splice sleeve and at the tap hole. Each accessible end of the splice sleeve or mechanical anchorage device must also be subjected to the maximum allowable void criteria as described in the construction specification. Splices and mechanically headed deformed bars not meeting these criteria must be removed and replaced.

2.5.5 Epoxy-filled coupling sleeve

Epoxy-filled coupling sleeves are broad steel sleeves that are injected with an epoxy adhesive to join the reinforcing bars. This splice is much like the grout-filled splice (Figure 2-19), with some companies using the steel sleeves interchangeably for both types of mechanical splices. Epoxy-filled splices benefit from shorter setting times than grout-filled splices; the splice can gain full strength within 4 to 12 hours depending on the temperature – warmer temperatures require less time than cooler ones. The epoxy used is usually proprietary. As discussed below, once in place, the epoxy filling may lose strength and stiffness when subjected to high temperatures and moisture. The splice should be inspected to ensure proper filling and interlock within the sleeve; typically, this is done by visual inspection for epoxy at the outlet hole and sleeve ends.

Epoxy-filled coupling sleeves are relatively new in construction, and the rapid setting time and ability to be placed in congested areas, coupled with the ability to use the splice without machining or rotating the bar, represent attractive advantages to the designer and constructor. Despite this, only one company is currently advertising an epoxy-filled splice:

- HRC® 620 Series

This splice is a Grade 60 coupler capable of meeting Type 2 criteria. A one-sided sleeve is friction-welded to the continuing bar for this splice. The sizes range from No. 4 to No. 9 (in.-lb), and No. 12 to No. 29 (SI). Other mechanical splices listed as grout-filled couplers may be used with an epoxy-fill, but no company other than HRC is currently advertising such an application.

A Japanese company that had offered an epoxy-filled splice removed the system from their website and literature during the course of writing this report. The lack of broad use by producers and engineers is likely due to the fact that this type of splice is relatively new and unproven; the splice's behavior and longevity are still under scrutiny. The limited number of studies that have been performed raise concerns over the durability of this splicing system. One study conducted by Brungraber [47] in conjunction with Caltrans (California Department of Transportation) examined the long-term behavior of epoxy-filled splices. Specimens were tested using modifications to methods outlined in ASTM E1512 [48], which governs epoxy anchorages to concrete. The study [47] evaluated moisture-induced degradation of six epoxies designed for use in concrete adhesive anchorages, with two of the six epoxies exposed to moisture (submerged in deionized water) and elevated temperature (ranging from 73 to 140 °F, 23 to 60 °C) over a period of 14.5 months. Brungraber found that the epoxy-filled splices initially met all criteria for mechanical splices listed in ACI 318 and AC133, including both tensile and cyclic loading criteria. Long-term testing of the epoxy-filled splices, however, indicated the potential for serviceability and structural concerns. Creep test results showed that some of the epoxies exhibited significantly greater slip than grout-filled splices, which could lead to increased cracking and deflection in a member. Changes in the strength and stiffness testing of the epoxies at elevated temperatures and under exposure to moisture showed that the epoxies were sensitive to both, with the amount of degradation increasing as the temperature increased. In some cases, over half of the tensile strength and nearly two-thirds of the stiffness of the epoxy at room temperature was lost when the epoxy was tested at 140 °F (60 °C). Epoxy-filled splices appear on the list of Caltrans-approved splices prior to 2008, they are no longer listed [49].

2.6 Summary

Table 2.1 summarizes the types and attributes of the available splice systems. The table indicates if each system meets the requirements of a Type 1 or Type 2 splice, as well as if the splice requires rotation of the bar during assembly, machining of the bar, a reduction in the cross-sectional area of the bar, a large spacing or clearance around the splice, or if the splice must be left undisturbed for a significant amount of time following assembly (typically for setting of grout or epoxy). The table also indicates if the splice has been used in nuclear power plants (NPP) or meets ASME BPV CODE SECTION III/ACI 359 [10] requirements for use in NPP, and if the splice is available for high-strength steels—those with a yield strength of at least 100 ksi [690 MPa]. For each system, a solid circle indicates that all splices of that type have the indicated attribute, while a hollow circle indicates that some splices of that type have that attribute. Consult individual sections and Appendix A for details on splices from specific producers.

From the table, it is clear that no single splice is best suited for all applications; for example, machining bars for new construction may not pose a significant challenge, whereas machining a bar partially cast in concrete during a repair or retrofit would be exceedingly difficult. This table will allow designers and contractors to see at a glance what categories of splices are best suited for their project.

Table 2-1
Quick reference to mechanical splices – types and attributes

Splice System	ACI 318 Type 1	ACI 318 Type 2	Bar Rotation	Bar Machining	Bar Area Reduction	Wide Clearance Needed	Long Setting Time	NPP Application[1]	≥ Grade 100 (Grade 690)
2.1 Cold-Swaged Couplers									
2.1.1 Cold-swaged steel coupling sleeve	●	○				●		○	
2.1.2 Cold-swaged coupler with taper-threaded ends	●	○	●					○	○
2.1.3 Extruded coupler with parallel-threaded ends	●	○	○					○	
2.2 Friction-welded Couplers									
2.2.1 Friction-welded bar coupler with taper-threaded ends	●	○	●					○	
2.2.2 Friction-welded coupler with parallel-threaded ends	●	○	○					○	
2.3 Screw/Wedge Sleeve Couplers									
2.3.1 Shear screw and rail coupling sleeve	●	○						○	
2.3.2 Shear screw and wedge coupling sleeve	●	○						○	○
2.3.3 Shear screw and double-wedge coupling sleeve	●					●			
2.3.4 Steel coupling sleeve with wedge	●					●			
2.3.5 Strap-type steel coupling sleeve	●								

● = All splices surveyed in this category have this requirement.
○ = Some splices surveyed in this category have this requirement. See Appendix A for individual splice details.
[1] Refers to splices listed as being used on previous commercial nuclear power plant projects or compliant with ASME BPV CODE SECTION III/ACI 359 [10].

Table 2-1 (continued)
Quick reference to mechanical splices – types and attributes

Splice System	ACI 318 Type 1	ACI 318 Type 2	Bar Rotation	Bar Machining	Bar Area Reduction	Wide Clearance Needed	Long Setting Time	NPP Application[1]	≥ Grade 100 (Grade 690)
2.4 Threaded Couplers									
2.4.1 Integrally forged coupler with flange	●	●	●	●	●				
2.4.2 Taper-threaded steel coupler	●	○	●	●	●			○	○
2.4.3 Parallel-threaded steel coupler	●	○	●	○	○			○	
2.4.4 Threaded coupler with standard national coarse threads	●	○	○	●				○	○
2.4.5 Threaded coupler with upsized bar threads, cold-forged	●	○	●	●				○	○
2.4.6 Coupler for thread-like deformed reinforcing bars	●	○	○					○	○
2.4.7 Upset bar and coupling sleeve with straight threads	●	●		●					
2.5 Filled Couplers									
2.5.1 Grout-filled coupling sleeve	●	○				●	●	○	
2.5.2 Grout-filled coupling sleeve with taper thread	●	○		●	●	●	●	○	
2.5.3 Grout-filled coupling sleeve with parallel thread	●			●	○	●	●	○	
2.5.4 Steel-filled coupling sleeve	●	●				●		●	●
2.5.5 Epoxy-filled coupling sleeve	●	●			●	●	●		

● = All splices surveyed in this category have this requirement.
○ = Some splices surveyed in this category have this requirement-see Appendix A for individual splice details.
[1] Refers to splices listed as being used on previous commercial nuclear power plant projects or compliant with ASME BPV CODE SECTION III/ACI 359 [10].

3
BARRIERS TO ENTRY FOR NEW MECHANICAL SPLICING SYSTEMS

This chapter identifies the barriers to entry of new and innovative mechanical splicing systems into the marketplace. Requirements of reinforced concrete design codes and regulatory bodies are examined; additional testing that would allow for broader acceptance of new splicing systems by the engineering community is also discussed.

3.1 Code and Regulatory Requirements

Compared to many other engineering systems, relatively few requirements are placed on mechanical splicing systems. The only requirements for the capacity of mechanical splices in ACI 318-14 [11] are listed in Sections 18.2.7 and 25.5.7. Section 18.2.7 of ACI 318-14, covering the use of mechanical splices in earthquake-resistant structures, requires that all mechanical splices be able to develop 125% of the yield strength of the bars being spliced; splices meeting this requirement are classified as Type 1 splices. A second classification, Type 2, is specified for splices intended for use in special moment frames and special structural walls. Type 2 splices must be capable of meeting Type 1 requirements and developing the full tensile strength of the bars being spliced. Sections 18.2.7, 18.9.2.1, 18.12.7.4, and 25.5.7 of ACI 318-14 place restrictions on the use or locations of mechanical splices, but pose no additional requirements on the design of the splice itself. Section 25.5.7 requires that splices on adjacent bars be staggered at least 30 inches when used in tension tie members. ACI 318-14 requirements are referenced by numerous international committees, including the International Code Council (ICC) within the International Building Code (IBC), International Residential Code (IRC), and the ICC AC133 Acceptance Criteria for Mechanical Splice Systems for Steel Reinforcing Bars [12], among others. ICC AC133 references these sections along with supplying other requirements to be recognized in an ICC Evaluation Service.

The acceptance criteria for mechanical splices, ICC AC133 [12], sets structural performance tests for mechanical splices. In addition to the strength requirements specified by ACI 318-14 [11], the elongation of the splice must be measured during testing, and a load-elongation plot must be supplied. Cyclic testing of all splices is required in addition to static tensile/compressive strength tests. Strength and elongation tests must be performed on all bar sizes for which certification is sought, and minimum sample sizes and testing intervals are specified. The acceptance criteria requires that splices be tested in accordance with ASTM A370 [50], which covers methods for mechanical testing of steel products. In addition to these general acceptance guidelines for mechanical splices, specific criteria for grout-filled mechanical splices are addressed. More specifically, the grout must be tested for minimum compressive strength and freeze-thaw resistance.

Much as is the case for Code acceptance, relatively few additional requirements are placed on the use of mechanical splices by the regulatory bodies governing the construction of nuclear power plants, and most of those requirements govern the use and placement of the splice within the structure, not the design of the splice itself. ACI 349-13 [44] details code requirements for nuclear safety-related concrete structures. Similar to ACI 318-14 [11], the only performance-related restriction on splicing systems is the requirement that all mechanical splices be able to develop 125% of the yield strength of the bars being spliced. ACI 349-13 also requires visual inspection of every splice and explicitly gives the engineer the right to require destructive tests on production splices to ensure compliance. Other restrictions on splice placement and spacing are similar to those found in ACI 318-14.

The American Concrete Institute and the American Society of Mechanical Engineers Boiler Joint Committee 359, Concrete Containments for Nuclear Reactors, are responsible for writing Section III, Division 2 of the ASME Boiler and Pressure Vessel Code, published as ACI 359-15 [10]. ACI 359-15 outlines additional requirements for mechanical splices. When spliced bars are carrying tensile stresses, only a mechanical splice or welded butt splice is explicitly permitted; other splices must be tested and demonstrate adequate strength prior to acceptance. When installing mechanical splices, the splice must be staggered if the splice would see a strain more than 50% greater than the strain at 0.9 times the yield strength of the bar. Where multiple parallel bars must be spliced, splices are prescribed to be staggered at least 30 inches.

ASME/ACI 359-15 [10] does place restrictions on the allowable types of mechanical splices, permitting only taper-threaded splices (Sections 2.2.1 and 2.4.2), swaged splices (Section 2.1), cold-roll formed parallel-threaded splices (Sections 2.4.1, 2.4.3, 2.4.4, and 2.4.5), or ferrous-filled (Section 2.5.4) or grout-filled (Sections 2.5.1, 2.5.2, and 2.5.3) sleeve splices for use with standard reinforcing bars (threaded splices are permitted for thread-deformed reinforcing bars (Section 2.4.6)). (Note: The terminology in Section III, Division 2 of the ASME Boiler and Pressure Vessel Code differs from that used in this report; the equivalent sections in this report are listed next to the ASME splice designations above.) Splice systems must be qualified under standard and cyclic tensile testing prior to use, with periodic retests of production splices throughout the project. Any worker installing a splice must be certified, and the constructor or fabricator is responsible for maintaining all records with regards to the qualification of the splices and the workers installing them.

3.2 Acceptance by the Broader Engineering Community

The relatively small number of requirements on mechanical splices in code and regulatory documents would seem to make it relatively easy for innovative splices to enter the market. In addition to the potential need to provide design guidance to engineers, this same lack of requirements, however, means a designer has no guarantee that a new mechanical splicing system will exhibit acceptable performance over the long term. As discussed in Section 2.5.5, research by Brungraber for Caltrans [47], for example, found that some of the epoxy-filled splice systems evaluated were susceptible to degradation in moist or high-temperature environments, resulting in excessive bar slip and loss of tensile capacity. None of these issues would be revealed under current code and regulatory testing criteria, which could lead to reduced service life or, potentially, structural failure. Brungraber recommended modifications to Caltrans acceptance criteria to specifically address moisture-induced degradation of epoxy systems; however, the recommendations do not cover other potential modes of failure for splice systems.

Broader testing should be performed prior to the widespread use of new and innovative splicing systems. Adoption of the cyclic testing outlined in ICC AC133 [12] would provide additional assurance that a new splicing system is capable of withstanding the variable loads present in most structures; currently, many state departments of transportation specify such a requirement. In order to increase the proper use of mechanical splices, a design guide developed by EPRI would benefit the structural designers for the global nuclear power fleet. In addition, to ensure adequate performance of any new mechanical splicing system, it is recommended that the system be subject to the following tests.

3.2.1 Full scale beam splice tests

Currently, mechanical splices are categorized as Type 1 or Type 2 splices based on a direct tensile or compressive test following ASTM A370 [50]. While this method is adequate for quality control and spot checking in-situ installation, many splices will be used in members subject to significant flexural demand in place of or in addition to direct axial load. To ensure adequate performance under all loading conditions, a series of full-scale beams should be cast with longitudinal bars spliced with a new splicing system. The testing can include different splicing systems (e.g., grouted, threaded) under various conditions (e.g., temperature increases, direct tensile or flexural). Test should cover the range of bar sizes suitable for the splice with the highest grade of steel with which the splices will be used. Companion beams with non-spliced bars from the same heat of steel as used in the spliced specimens should be cast as controls. Such specimens were integral in the acceptance of ASTM A1035 steel by the engineering community [51, 52]. (Note that the test program used for the qualification of ASTM A1035 steel was far larger than would be needed for a new splicing system.) These tests would not be necessary for a system designed to be used in compression only.

3.2.2 Creep tests

Excessive creep in a mechanical splice poses serious serviceability and structural concerns for reinforced concrete structures, ranging from increased cracking and deflection to loss of load transfer between bars and member failure. Currently, no standard test for creep of mechanical splices exists, and new splice systems do not have to demonstrate adequate performance under long-term loading. While creep may not be as much of a concern for splices with direct metal-to-metal contact between the bar and splice as it would be for grouted or epoxy-filled systems, even the connections in direct metal-to-metal contact systems should be evaluated for slip over time. Brungraber [47] used a modified version of a test for evaluating the creep of concrete adhesive anchors [48] to evaluate creep in epoxy-filled mechanical splices and found that some epoxies exhibited unsatisfactory creep performance, which could lead to long-term performance issues if the epoxy systems were used in practice. It is therefore recommended that any new splicing system be evaluated under a test protocol similar to the one used by Brungraber [47] prior to use in a structure.

3.2.3 Other tests

Several environmental resistance tests in ASTM E1512 for adhesive anchors should be considered for modification and used to evaluate new mechanical splices prior to acceptance. This is a particular concern for epoxy-filled splices; moisture-related failures of adhesive anchors have been well studied [53, 54], and could pose a similar concern when epoxies are used in mechanical splices. Many epoxies that have been used in experimental mechanical splices are intended for use in adhesive anchors; such epoxies are required to demonstrate moisture resistance per ASTM E1512 [48]. Regardless, a modified test for splices should be developed to ensure adequate performance. Such a test would also identify systems that were particularly susceptible to corrosion.

Another concern in regard to mechanical splices is elevated temperature. As with moisture-related issues, elevated temperature is of particular concern for epoxy-filled splices. Brungraber [47] found that many of the epoxy systems that were tested lost significant strength and stiffness when exposed to moisture at elevated temperatures [140 °F (60 °C)]. In some cases, over half of the ultimate tensile strength and nearly two-thirds of the stiffness of the epoxy at room temperature were lost when the epoxy was tested at 140 °F (60 °C). This is a particular concern in nuclear power plants, where elevated temperatures are expected in some areas of the site. It is imperative, therefore, that epoxy-filled splices be evaluated at the service temperature of the structure. Other splicing systems may also be susceptible; for example, differences in coefficients of thermal expansion between the reinforcement and the splice (or between different parts of the splice itself for splices not made from a single alloy) may result in a looser fit and increased slip at elevated temperatures.

ASTM E1512 [48] also specifies an optional test for radiation exposure. It is highly recommended that new mechanical splices be evaluated using a modified version of this test prior to use in nuclear power plant facilities if there is any concern that one or more of the components of the splice could be affected by radiation.

4
SUMMARY AND CONCLUSIONS

Mechanical splices are used in reinforced concrete members where continuous reinforcement is needed and lap splices are not desirable. Mechanical splices allow for reduced material use, help decrease congestion, and in some cases will reduce unnecessary delays in construction and repair. There are dozens of different methods by which mechanical splices achieve interlock with the reinforcing bars being spliced. Currently, there are limited resources for assisting the designer or contractor in choosing an appropriate mechanical splice for a project. This report presents the results of a world-wide survey that included 29 companies and examines a total of 91 splicing systems sorted into 22 categories based on the splice configuration and mechanism by which the splice achieves force transfer. Each category of splice is described; placement requirements and suitable uses are also discussed. In addition, barriers to entry of new splicing systems into the market are identified, and test methods to evaluate the suitability of new splicing systems are proposed.

Based on the results of this research, the following conclusions can be drawn:

1. A wide variety of mechanical splicing systems are available; this report helps the designer to select splice systems that are suited to the project conditions. Selection of an optimum splice system can reduce construction time and cost of the project. The reduced construction delays is achieved through reduced likelihood of construction repairs. The delays associated with splicing reinforcing steel can potentially be avoided by selecting mechanical splicing options which are quicker to install.
2. No single splicing system is best-suited for all projects.
3. Current code and regulatory provisions pose relatively few barriers for entry of new splicing systems. However, additional tests are needed to ensure adequate long-term performance and durability of new splicing systems.
4. Insufficient data exists to recommend the unrestricted use of epoxy-filled splicing systems. Given the wide range of results in the literature, specific epoxy-splice systems should be selected for thorough evaluation prior to use in a structure.
5. Based on the findings of this work, additional research is suggested. The proposed research and development includes development of design guidance to aid structural designers in using mechanical splices for their designs. Additionally, empirical testing is recommended to indicate adequacy of mechanical splices for specific structural scenarios. These tests include full-scale splice tests for flexural members, creep tests of splices for long-term serviceability, and environmental resilience to excessive temperature and radiation.

5
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A
INDIVIDUAL SPLICE ATTRIBUTES

This appendix summarizes the available data from each splice producer for each splice system. For each splice, the ACI 318 type (or types, if a company makes multiple versions of the same splice), range of bar sizes and grades, and dimensions for a No. 8 (No. 25) splice are provided. (The dimensions are intended to provide a relative comparison between splices; a No. 8 (No. 25) splice was chosen because every splice in this study was available in that size). A hyphen is shown where a manufacturer did not provide information. In the body of the report, only standard bar sizes (those listed in the governing ASTM standard for the bar) are listed; the full range of available sizes, including nonstandard sizes, is provided in the following tables.

Table A-1
Cold-swaged steel coupling sleeve properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
BarGrip XL	BarSplice Products, Inc.	Type 2	No. 3-18	No. 10-57	60, 75, 80	-	1.75 (44)	7 (178)
GripLock SL	BARUS LLC	Type 1	No. 4-18	No. 12-50	60	-	1.75 (44)	5.38 (135)
Pressed BarLink SBT	Best Notch Group	Type 1	-	-	-	-	-	-
RepairGrip	Dextra Group	Type 1	-	No. 12-40	-	500	- (45)	- (160)
FLIMU® System	DYWIDAG (DSI)	Type 1	-	No. 16-50	-	500	- (45)	- (160)
R Type	Fuji-Bolt	Type 1	-	-	-	-	-	-
Moment® Bargrip	Halfen-Moment Inc.	Type 1	-	No. 16-40	-	-	- (45)	- (140)
KZ Hydraulic-grip rebar coupler	KZ International	Type 1	-	No. 16-57	-	-	- (45)	- (140)
Cold stamping rebar coupler	OCEPO®	Type 1	-	No. 16-40	-	335, 400, 500	- (45)	- (150)
Bar swage mechanical splice	Preshcon Industries	Type 1	-	No. 16-40	-	-	- (45)	- (170)

Table A-2
Cold-swaged coupler with taper-threaded ends properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
GripTwist®	BarSplice Products, Inc.	Type 2	No. 3-18	No. 10-57	60, 75, 80	-	1.75 (45)	5.69 (145)
GripTwist®	BarSplice Products, Inc.	Type 2	No. 4-18	No. 13-57	80, 100, 120	-	2.19 (-)	12.4 (-)
KZ Hydraulic-grip rebar coupler	KZ International	Type 1	-	No. 16-57	-	-	- (45)	- (180)

Table A-3
Extruded coupler with parallel-threaded ends properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
GripLock™	BARUS® LLC, Inc.	Type 2	No. 4-18	No. 12-50	60	-	1.75 (44)	5.38 (138)
Griptec	Dextra Group	Type 1	No. 4-18	-	60	420, 500	-	-
INCON ICS	INCON	Type 1	No. 3-11	No. 10-40	60, 75	-	1.65 (42)	8.98 (220)
FD Grip	Fuji-Bolt	Type 1	-	-	-	-	-	-
C-S Joint	OCM, Inc.	Type 1	-	No. 13-51	-	SD295A, SD295B, SD345, SD390	-	-
MODIX® rebar coupler	Peikko® Group	Type 1	-	No. 10-40	-	450, 500, 550	- (41)	- (218)
KZ Hydraulic-grip rebar coupler	KZ International	Type 1	-	No 16-57	-	-	- (45)	- (210)

Table A-4
Friction-welded bar coupler with taper-threaded ends properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
HRC® 400 Series	Headed Reinforcement Corp. ®	Type 1	No. 5-18	-	60, 75	-	2.25 (-)	3.5 (-)
HT Coupler	Hy-Ten	Type 2	-	No. 16-50	75	500	- (34)	- (70±3)
KZ Friction-welding rebar coupler	KZ International	Type 1	-	No. 16-57	-	-	-	- (67)

Table A-5
Friction-welded bar coupler with parallel-threaded ends properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
HRC® 400 Series	Headed Reinforcement Corp. ®	Type 1	No. 10-18	-	60, 75	-	-	-
HT Coupler	Hy-Ten	Type 2	-	No. 16-50	75	500	- (36)	- (95±3)
KZ Friction-welding rebar coupler	KZ International	Type 1	-	No. 16-57	-	-	-	- (110)
E-Splice™	NatSteel	Type 2	-	No. 16-40	-	-	- (36)	- (65)

Table A-6
Shear screw and rail coupling sleeve properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
Mechanically Bolted Coupler	Ancon®, Ltd.	Type 2		No. 10-40	60	-	- (54)	- (258)
Jawws™ Shear Screw System	BARUS®, Ltd.	Type 1	-	No. 12-58	60	-	-	-
D250L Bar Lock® coupler	Dayton Superior®	Type 1	No. 3-18	No. 10-57	60	-	2.24 (-)	12.28 (-)
D250XL Bar Lock® coupler	Dayton Superior®	Type 2	No. 3-18	No. 10-57	75, 80	-	2.4 (-)	18.7 (-)
D250S/CA Bar Lock® coupler	Dayton Superior®	Type 2	No. 3-18	No. 10-57	60	-	2. 4 (-)	10.2 (-)
D630 Compression Only Coupler	Dayton Superior®	Type 2*	No. 4-18	No. 10-57	60	-		-
Unitec	Dextra Group	Type 2	No. 4-18	No. 12-50	60	-	2.5 (62)	9.5 (220)
LENTON LOCK Shear Bolt Splicing System	Pentair	Type 2	No. 4-18	No. 12-57	60	-	2.13 (-)	10 (-)

*Compression only

Table A-7
Shear screw and wedge coupling sleeve properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
Zap Screwlok®	BarSplice Products, Inc.	Type 2	No. 3-18	No. 10-57	60, 75	-	2.25 (57)	15.25 (388)
Zap Screwlok® SL	BarSplice Products, Inc.	Type 1	No. 4-18	No. 12-57	60	-	2.25 (57)	13 (330)
Zap Screwlok® FX	BarSplice Products, Inc.	Type 1 Type 2	No. 4-18	No. 10-57	T1:100 T2: 75, 80	-	2.25 (57)	15.25 (388)

Table A-8
Shear screw and double-wedge coupling sleeve properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
Double Barrel Zap	BarSplice Products, Inc.	Type 1	No. 3-8	No. 10-25	60	-	3.13 (79)	6.5 (165)

Table A-9
Steel coupling sleeve with wedge properties

Product Name	Company	Type	Bar Size Range		Grade		No. 6 (No. 16) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
LENTON QUICK WEDGE Mechanical Lap Splice	Pentair	Type 1	No. 4-6	-	60	-	2.38 (-)	2.75 (-)

Table A-10
Strap type steel coupling sleeve properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
LENTON SPEED SLEEVE - Compression only	Pentair	Type 1*	No. 6-18	No. 20-57	-	-	2.18 (-)	6.06 (-)

*Compression only

Table A-11
Integrally forged coupler with flange properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
D50 DBR™ Coupler System	Dayton Superior®	Type 2	No. 4-11	No. 13-36	60	-	1.59 (-)	2.06 (-)
DBDI™ Splice System	Dayton Superior®	Type 2	No. 4-11	No. 13-36	60	-	1.59 (-)	2.06 (-)

Table A-12
Taper-threaded steel coupler properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
Ancon Taper-Thread Couplers	Ancon®, Ltd.	Type 1	-	No. 12-50	-	500	- (36)	- (90)
Ancon Cryogenic Couplers	Ancon®, Ltd.	Type 1	-	No. 12-32	-	500	- (36)	- (90)
BARUS TTEX™ System	BARUS®, LLC. Inc.	Type 1	-	No. 12-58	60	-	-	-
D310 Taper-Lock® Coupler	Dayton Superior®	Type 2	No. 4-18	No. 13-57	60	-	3.62 (92)	-
Moment® Spearline	Halfen-Moment, Inc.	Type 2	-	No. 12-40	-	420, 500, 550	- (32)	- (75)
KZ Threaded rebar coupler	KZ International	Type 1	-	No. 18-40	-	500	- (36)	- (66)
Lenton Taper-threaded splicing systems	Pentair	Type 2	No. 3-18	No. 10-57	60, 75, 80, 100, 120	-	1.5 (-)	3.8 (-)
Taper Threaded Couplers	Spplicetek™	Type 1 Type 2	-	No. 16-40	-	-	- (36)	- (85)

Table A-13
Parallel-threaded steel coupler properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
Rolltec	Dextra Group	Type 2	-	-	-	-	-	-
Moment® JoinTec	Halfen-Moment, Inc.	Type 2	-	No. 12-40	-	420, 500, 550	- (40±1)	- (60±1)
Moment® Rebartech coupler	Halfen-Moment, Inc.	Type 2	-	No. 12-50	-	420, 500, 550	- (40±1)	- (60±1)
KZ Threaded Rebar Coupler	KZ International	Type 1	-	No. 18-39	-	-	- (40)	- (60)
Parallel Thread Rebar Coupler	OCEPO®	Type 1	-	No. 16-40	-	335, 400, 500	- (37)	- (63)
ReidBar™ Couplers	ReidBar™	Type 1	-	No. 12-32	-	500	- (45)	- (180)
Parallel threaded steel couplers	Yau Lee Metals and Building Materials	Type 1	-	-	-	-	-	-

Table A-14
Standard national coarse threads properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
BPI® BarSplicer	BarSplice Products, Inc.	Type 2	No. 4-11	No. 12-36	60, 75, 80	-	1.5 (38)	3 (76)
BPI® Stainless BarSplicer	BarSplice Products, Inc.	Type 1	No. 4-11	No. 12-36	60, 75, 80	-	1.5 (38)	3.5 (89)
BPI® 100 ksi BarSplicer	BarSplice Products, Inc.	Type 1 Type 2	No. 4-11	No. 12-36	T1: 100 T2: 60, 75, 80	-	1.5 (38)	3 (76)
GEWI® Threadbar System	DYWIDAG (DSI)	Type 2	-	No. 16-50	-	500, 670, 800	- (42)	- (150)
HRC® 300 Series	HRC	Type 2	No. 4-8	-	60, 75	-	1.5 (-)	3 (-)
RC-53 Threaded rebar coupler	MeadowBurke®	Type 1	No. 4-11	-	60	-	1.5 (-)	3.25 (-)

Table A-15
Threaded coupler with upsized bar threads, cold-forged properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
BT Stainless Steel Coupler	Ancon®, Ltd.	Type 1	-	No. 16-40	-	500	- (36)	- (48)
Bartec Plus	Ancon®, Ltd.	Type 1	-	No. 16-40	-	500	- (40)	- (60)
Bartec	Ancon®, Ltd.	Type 2	-	No. 12-50	-	500	-	-
CXL Couplers	Ancon®, Ltd.	Type 2	-	No. 12-50	-	500	- (42)	- (60)
Hérisson®	Armaturis®	Type 1	-	No. 12-40	-	-	- (42.3)	- (100.65)
Hérisson®+ Mono	Armaturis®	Type 1	-	No. 12-40	-	-	- (42.3)	- (87.65)
Firsty®	Armaturis®	Type 1	-	No. 12-40	-	-	- (40.5)	- (65.65)
SimGrip™	BARUS® LLC., Inc.	Type 1	No. 4-18	No. 12-50	-	-	1.38 (36)	2.38 (59)
Threaded Barlink SBT Coupler	Best Notch Group	Type 1	-	-		-	-	-
Bartec	Dextra Group	Type 2	No. 4-18	-	60, 75, 80, 100	420, 500, 550, 670, 800	1.63 (-)	2.75 (-)
Fortec	Dextra Group	Type 2	No. 4-18	-	60	420	-	-
MECH-JOINT	Hi-Tech	Type 2	-	-	-	420, 500, 550	-	-
INCON IBS	INCON	Type 1	-	No. 12-50	60, 75	-	- (41)	- (60)
Upset Forging Rebar Coupler	OCEPO®	Type 1	-	No. 16-40	-	335, 400, 500	- (41)	- (60)
'IRON MAN' BMS	Preshcon Industries	Type 2	-	No. 16-50	60	-	- (38)	- (58)
Cold Forged Parallel Thread Coupler	Spplicetek™	Type 1	-	-	-	-	-	-

Table A-16
Coupler for thread-like deformed reinforcing bars properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
Threaded bar and accessories	Skyline Steel	Type 2	No. 8-28	-	75, 150	-	1.63 (41.3)	4.5 (114.3)
Threaded bar with fasteners	Williams Form Engineering Corp.	Type 1 Type 2	No. 4-28	No. 13-57	60, 75, 90, 150	-	1.63 (41.3)	3.88 (98.4)
SAS Threadbars	SAS Stressteel, Inc.	Type 2	No. 5-24	No. 12-75	75, 80, 97	500, 550, 670	- (41)	- (175)

Table A-17
Upset bar and coupling sleeve with straight threads properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
HRC® 500 XL/510 XL	Headed Reinforcement Corp.	Type 2	No. 4-14	-	60	-	2.5 (60)	2.38 (90)
HRC® 520/525 Form Protector	Headed Reinforcement Corp.	Type 2	No. 5-14	-	60	-	2.13 (54)	4.25 (120)

Table A-18
Grout-filled coupling sleeve properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
D410 Sleeve-Lock®	Dayton Superior®	Type 2	No. 4-18	No. 13-57	60	-	2.89 (-)	16.52 (-)
M Type	Fuji-Bolt	Type 1	-	-	-	-	-	-
ReidBar™ Grouters	ReidBar™	Type 2	-	No. 12-32	-	500	- (42±3)	- (360)
NMB Splice-Sleeve	Splice Sleeve	Type 2	No. 5-18	-	60	-	2.52 (-)	14.57 (-)

Table A-19
Grout-filled coupling sleeve with taper thread properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
Ancon Grout Sleeve Coupler	Ancon® Ltd.	Type 1	-	-	-	500	-	-
LENTON INTERLOK Grout-fill	Pentair	Type 2	No. 5-18	No. 16-57	-	420, 500, 550	2.69 (-)	8.62 (-)

Table A-20
Grout-filled coupling sleeve with parallel thread properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
Groutec	Dextra Group	Type 1	-	No. 12-40	-	420, 500, 550	- (68)	- (220)

Table A-21
Steel-filled coupling sleeve properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
LENTON CADWELD Metal-filled Splice System	Pentair	Type 2	No. 5-18	No. 16-57	-	-	1.88 (-)	5 (-)

Table A-22
Epoxy-filled coupling sleeve properties

Product Name	Company	Type	Bar Size Range		Grade		No. 8 (No. 25) bar splice	
			in.-lb	SI	in.-lb	SI	Diameter, in. (mm)	Length, in. (mm)
HRC® 620 Series	Headed Reinforcement Corp.	Type 2	No. 4-9	No. 12-29	60	-	2 (51)	6.5 (165)

Export Control Restrictions

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