TECHNICAL GUIDE

REBAR COUPLER SYSTEMS

BAR
BRITISH ASSOCIATION OF REINFORCEMENT
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First published December 2020

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The British Association of Reinforcement (BAR) is the trade association of UK manufacturers and fabricators of steel reinforcement products including cut and bent bar and mesh.

BAR aims to add value to the reinforcement industry through market and product development, promotion of good industry and health and safety practices and forwarding the development of the reinforced concrete industry as a whole.

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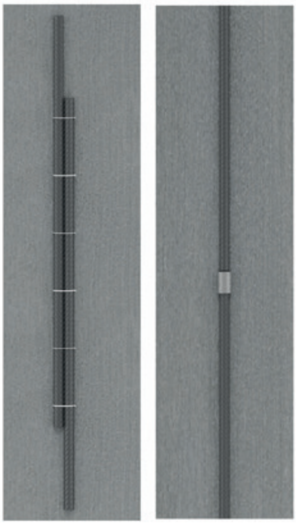
1. PRINCIPLE

Reinforced concrete design and construction practice has historically focused on the use of lap splicing as a method of transferring load between reinforcement bars. This relies on the load being transferred from one rebar, through the surrounding concrete and into the adjacent lapped rebar. However, the lapping of reinforcement is not always the most appropriate splicing method and there are many situations where the use of mechanical rebar couplers is more desirable from a design perspective, more convenient from a construction perspective, or both.

Rebar coupler systems, sometimes also known as mechanical splices, are used as an alternative to traditional lap splices in concrete. They transmit the rebar load directly from one rebar to another without relying on concrete bond, concrete strength, or the condition of the concrete surrounding the rebar and coupler.

Lap splices rely on the rebar / concrete bond and concrete integrity to transfer the load from one rebar to the other

Transverse reinforcement in the lap zone has been omitted for clarity



Mechanical couplers ensure structural continuity without relying on concrete bond or concrete integrity to ransfer the load

Figure 1. Lap splice and the equivalent rebar coupler system

2. ADVANTAGES

There are many well documented advantages to using rebar coupler systems. These include:

2.1 Rebar Continuity

Reinforced concrete design codes of practice, including Eurocode 2[1], assume that the detailing, quality of materials and workmanship is such that the transmission of forces from one rebar to the other is assured. However, if the bond between the concrete and the rebar is lost, as a result of concrete cracking, deterioration, poor on site workmanship, rebar corrosion and subsequent spalling etc. then the rebar splice may fail. Rebar couplers do not rely on concrete bond and therefore they create more reliable rebar continuity.

2.2 Avoidance of transverse splitting forces

Many structural concrete codes of practice recommend the use of rebar couplers as an alternative to lapping, particularly for large rebar diameters where splitting and dowel action forces can be significant. Eurocode 2 states: *"Generally large diameter bars should not be lapped. Exceptions include sections with a minimum dimension 1.0m or where the stress is not greater than 80% of the design ultimate strength"* and *"Splitting forces are higher and dowel action is greater with the use of large diameter bars"*[2].

2.3 Reduction of rebar congestion

Lapping rebar in heavily reinforced sections can cause significant congestion, resulting in problems fixing the steel and insufficient room for the proper placement and compaction of the concrete. The use of rebar couplers will significantly reduce congestion making the placement and compaction of the concrete easier, leading to less risk of concrete segregation due to over vibration and as a result an increase in the concrete quality.

Figure 2. The use of rebar couplers can reduce rebar congestion as it eliminates the requirement to lap rebar.

1. EN 1992-1-1 Eurocode 2: Design of concrete structures. Part 1-1: General rules and rules for buildings
2. EN 1992-1-1 defines large diameter rebar as that having a diameter greater than 32mm. National Annexes may differ.

2.4 Safety

On site safety during construction is paramount. The use of rebar couplers can contribute to enhancing site safety:

- Rebar protruding through shuttering, which can be hazardous, can be eliminated by using couplers butted up against the shuttering or formwork, allowing the connection of the adjoining rebar after the shuttering or formwork is removed.
- On site welding of rebar can be eliminated by joining prefabricated cages with rebar couplers.

As well as construction site safety, rebar couplers are often seen as a safer alternative to lapping as do not rely on concrete bond and therefore they create more reliable rebar continuity – see section 2.1.

2.5 Ease of construction

The safety advantages of rebar couplers do not come at the expense of constructability. In fact, the use of rebar couplers can make on or off-site construction easier and faster as well as safer.

- Prefabricated rebar cages can be easily connected on site making on-site welding of rebar unnecessary.
- Individual concrete elements and construction joints can be joined without the need to drill through shuttering.
- The use of couplers allows for the face of concrete elements to remain smooth during construction, making construction easier and faster.

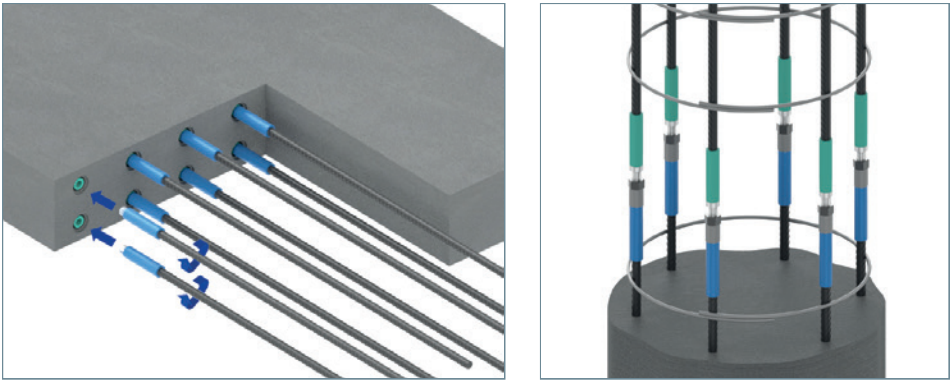


Figure 3.

(i) The use of couplers at concrete faces means that concrete elements can be joined without the need to drill through formwork.

(ii) Couplers can be used to join prefabricated cages on site, making on-site welding unnecessary.

2.6 Reduction in steel use

The use of rebar couplers reduces steel consumption and can therefore be an environmentally friendly and more sustainable option than lapping. The steel saved is equivalent to the lap length.

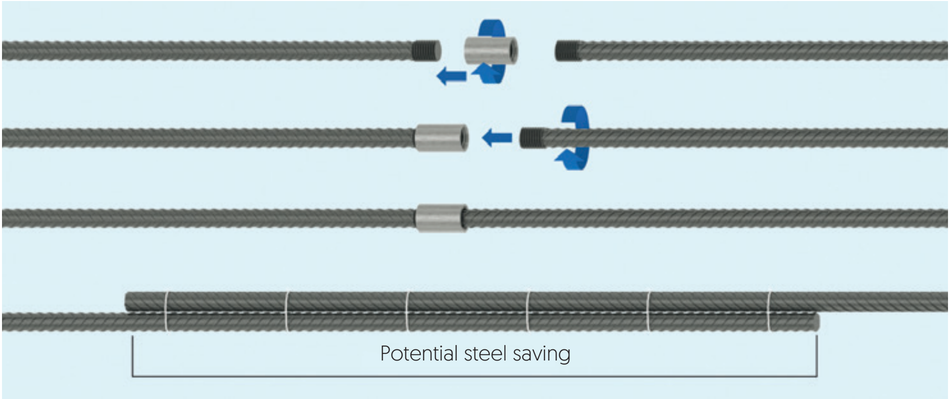


Figure 4. The use of rebar couplers allows for the effective use of material and a reduction in the quantity of steel used.

2.7 Seismic use

The scope of Eurocode 8[3] is to protect human lives, limit damage and ensure that structures important for civil protection remain operational, but it also recognizes that:

"The random nature of the seismic events and the limited resources available to counter their effects are such as to make the attainment of these goals only partially possible and only measurable in probabilistic terms." [Clause 1.1.1].

Severe cracking and the degradation of concrete elements is therefore possible. In such cases, the bond between the rebar and the concrete may be compromised and this in turn will compromise the ability of a lap splice to transfer load from one bar to another, and thus compromise the ability of the element to carry load. Mechanical rebar couplers do not rely on rebar bond with the concrete in order to transfer the load from one bar to the other and are therefore seen as a safer option to lap splicing in seismically designed structures provided they are a full capacity "bar break" system.

If conventional lap splicing is employed, the seismic design of reinforced concrete structures will often exacerbate reinforcement congestion problems. In addition, the significant increase in lap lengths and other codified detailing requirements can lead to over-reinforced concrete and a potential for non-ductile, brittle behavior at the lap splice region due to the concentration of stresses at both ends of the lap, inadvertently altering the elements deformation capacity. In such cases the use of mechanical rebar couplers is therefore seen as a distinct advantage.

3. EN 1998-1 Eurocode 8: Design of structures for earthquake resistance. Part 1: General rules, seismic actions and rules for buildings.t

The ductility of reinforcement is of significant importance in seismic design, with the reinforcement ductility requirements increasing as the requirement for energy dissipation increases as a result of greater seismic loading.

Eurocode 8 clause 5.2.3.4 states that:

"The steel used in critical regions of primary seismic elements should have high uniform plastic elongation"

Eurocode 8 clause 5.6.3 states:

"There may be splicing by mechanical couplers in columns and walls, if these devices are covered by appropriate testing under conditions compatible with the selected ductility class"

Note that in this context the ductility class is that associated with the structure, as defined by Eurocode 8 i.e. DCL, DCM or DCH.

The only way to retain the full ductility of the rebar, and therefore remain compatible, when connected with a mechanical coupler, is to ensure that it retains the ability to be taken to its ultimate tensile stress and not reduced in capacity as a result of a stress raiser or loss of rebar cross section at the mechanical rebar coupler. In other words, the coupler needs to be what is commonly known as a "bar break system", that is, a system which exceeds the ultimate tensile strength of the actual rebar it is connected to, ultimately forcing a tensile failure to occur in the rebar away from the influence of the coupler splice.

Thus, only full capacity "bar break" systems should be used in seismically designed reinforced concrete structures, as these are the only types of systems whereby the ductility of the connecting rebar is not compromised.

2.8 Advantages summary

Mechanical rebar couplers create a continuity of reinforcement which is not reliant on the quality or integrity of the concrete. Their use creates less rebar congestion, more convenient and often safer site practice as well as reducing the amount of steel used. Their use is not just allowed by European codes of practice but is also recommended under certain circumstances. While different performance levels exist for rebar couplers, a guaranteed "bar break" coupler means that there will ultimately be no brittle failure in a 'beyond design" event and the full ductility of the rebar will be maintained, a feature which is recommended in safety critical applications or if the structure could be subject to impact damage or a seismic event.

3. TYPES

Clause 8.7.1 of Eurocode 2 allows the forces to be transmitted from one rebar to another by the lapping or welding of rebar as well as the use of *"mechanical devices assuring load transfer in tension-compression or in compression only"*. However, compression only couplers are not used or certified for use in the UK.

Tension-compression couplers can broadly be broken down into:

[a] Couplers requiring rebar end preparation such as threading or the extrusion of sleeves onto the end of the rebar.

[b] Repair couplers requiring no rebar end preparation.

[c] Grouted couplers, requiring one or both adjoining rebars to be grouted into the coupler.

Different rebar coupler systems achieve different levels of performance, as discussed in Section 4. In addition, some coupler systems have in-build quality control features whereby each and every connection is automatically and systematically proof loaded by the processing machinery as part of a quality control procedure.

3.1 Couplers requiring rebar end preparation

Coupler systems requiring rebar end preparation are usually the most cost effective, but their use needs to be pre-planned as the bar end processing usually occurs at the rebar cut and bend depot and supplied to site with the appropriate rebar. These cut and bend fabricators would usually hold a stock of couplers and have the machinery to process the bar ends to suit the coupler system.

Each system is typically available in a number of different configurations. These are:

- Standard [as shown in the diagrams below].
  Standard couplers require the adjoining rebar to be rotated to form the connection.
- Positional.
  Positional coupler systems do not require the rotation of the adjoining rebar.
- Bridging.
  Bridging coupler systems will allow the adjoining rebar to be connected without rotation while also bridging a gap.
- Transition.
  Transition couplers allow connection between different rebar diameters.

- Examples of standard couplers systems which require rebar end preparation are as follows:

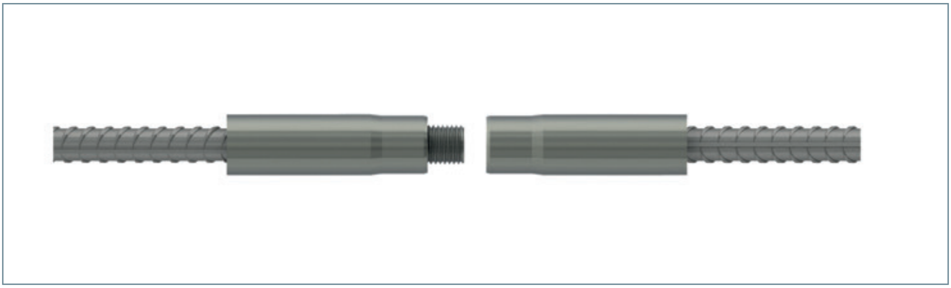


Figure 5. Cold Extruded Sleeve System
Male and female sleeves are extruded onto the rebar ends

Figure 6. Parallel Threaded System on Upset Rebar Ends
The ends are the rebar are cold forged to increase their diameter prior to threading

Figure 7. Parallel Thread System
Parallel threads applied directly the rebar ends with associated rebar coupler unit. The threads are typically rolled rather than cut onto the rebar.

Figure 8. Taper Thread System (Nvent Lenton)
Taper thread applied directly to the rebar ends with associated threaded coupler unit

3.2 Repair couplers requiring no rebar end preparation

While couplers requiring no rebar end preparation offer convenience on site to overcome construction issues and unplanned splicing where the appropriate lap lengths cannot be achieved, they tend to be both dimensionally larger as well as more expensive that coupler systems requiring rebar end preparation.

Figure 9. Bolted Sleeve System
Requiring no rebar end preparation, this type of system can be used to connect rebar on site by placing the rebar within the sleeve and tightening the hexagonal headed screws until a specific torque is achieved, or the screw head shears off.

3.3 Grouted Couplers

Grouted couplers are typically used for precast concrete applications to connect concrete elements and assure rebar continuity. Typically, one rebar is grouted into the coupler while the other is connected via a threaded connection. However, couplers where both rebars are grouted are also available.

Figure 10. Grouted Coupler
Grouted couplers are typically used for precast concrete applications. One or sometimes both rebars are grouted into a sleeve.

4. UK PERFORMANCE REQUIREMENTS

For UK projects, the performance requirements of mechanical rebar couplers are covered by the product standard BS 8597: 2015[4]. This includes a range of mandatory and optional performance requirements, depending on the application or level of performance required. These requirements are based on the use of BS 4449[5] or BS 6744[6] rebar.

4. BS 8597:2015 Steel for the reinforcement of concrete – Reinforcement couplers – Requirements and test methods
5. BS 4449: 2005 Steel for the reinforcement of concrete – Weldable reinforcing steel – Bar, coil and decoiled product - Specification
6. BS 6744: 2016 Stainless steel bars for the reinforcement of and use in concrete – Requirements and test methods.

Mandatory requirements are:

- Tensile strength
- Residual elongation (often referred to as slip) after tensile loading to 0.65 x characteristic yield strength of the reinforcing bar and unloading to zero load. The requirement being for a value ≤ 0.10mm or for a strain less than 0.16% or the actual strain measured on the reference bar, whichever is the greater.

Optional requirements are:

- Compression residual elongation (slip), with the same parameters as above.
- Fatigue

All tests are conducted in air, rather than in concrete.

4.1 Strength, ductility, and Fatigue Performance Requirements

The tensile strength requirements within BS 8597 are expressed in terms of rebar stress, with the tensile strength/yield strength ratios taken from the rebar product standard BS 4449 (in the case of carbon steel assemblies). For initial product assessment (qualification testing), a 99% characteristic value, based on a minimum of three assembly tensile tests is used, and for continuous assessment a 95% value is used.

Tensile strength requirements for rebar coupler assemblies

Rebar Standard	Grade	Tensile/yield stress ratio	Characteristic* strength (Mpa)
BS 4449	B500A	1.05	525
BS 4449	B500B	1.08	540
BS 4449	B500C	1.15	575

*99% characteristic strength value for qualification testing and 95% for continuous surveillance

BS 8597 gives no strength performance categories. Given that the ultimate tensile strength of B500 rebar can vary dramatically (for example BS4449 allows for the ultimate tensile strength of B500C rebar to vary between 575Mpa and 897Mpa), this means that there can be a variety of tensile strength performance characteristics of rebar couplers certified for use with B500 rebar. If a higher tensile performance level/greater factor of safety is required, then a “bar break” coupler system should be specified, which requires a tensile failure to occur in the rebar away from the influence of connection or bar end processing. This failure mode is defined in BS 8597 and the failure mode is recorded on laboratory test certificates.

The percentage elongation at maximum force (A_{gt}) is the principle measure of BS 4449 rebar ductility and it should be noted that if the rebar coupler system fails before the rebar, the rebar will not reach its maximum force and will therefore exhibit a reduction in A_{gt} ductility. The only way to maintain the full A_{gt} of the rebar “system” is to have a “bar break” rebar coupler system. It should also be noted that there is no mandatory BS 8597 rebar coupler system ductility requirement.

BS 8597 details three fatigue classes.

Class F is in accordance with the requirement within BS EN 1992-1-1.

Classes D and R are taken from the requirement for highway structures on UK motorways and trunk works.

Class D couplers are suitable for limited fatigue loading and therefore the designer may have to undertake a fatigue assessment.

Class R couplers can be treated as a continuous rebar for design purposes.

5. UK CERTIFICATION

At the time of writing the British Board of Agreement (BBA) and the Certification Authority for Reinforcing Steels (CARES) certify rebar coupler systems in accordance with the requirements of BS 8597.

CARES implement approval schemes called TA1-A and TA1-B which include quality control and quality assurance measures for both the product and the manufacturer.

CARES require that all testing is conducted with rebar of a specific ductility class (B or C) and upon successful testing, approval is given for the coupler system with the only the ductility class tested.

5.1 CARES TA1-A

Mandatory requirements are:

- Tensile strength
- Residual elongation (often referred to as slip) after tensile loading to 0.65 x characteristic yield strength of the reinforcing bar and unloading to zero load. The requirement being for a value ≤ 0.10mm or for a strain less than 0.16% or the actual strain measured on the reference bar, whichever is the greater.
- Fatigue.

It should be noted that TA1-A covers fatigue classed D and R only and at the time of writing all TA1-A approved couplers comply with class D only.

Optional requirements are:

- Compression residual elongation (slip), with the same parameters as above.

5.2 CARES TA1-B

Mandatory requirements are:

- Tensile strength
- Residual elongation (often referred to as slip) after tensile loading to 0.65 x characteristic yield strength of the reinforcing bar and unloading to zero load. The requirement being for a value ≤ 0.10mm or for a strain less than 0.16% or the actual strain measured on the reference bar, whichever is the greater.

Optional requirements are:

- Compression residual elongation (slip), with the same parameters as above.

5.3 UK Nuclear civil works requirements

The CARES TA1-C scheme is designed to certify rebar couplers as compliant with the requirements of the Sellafield specification for rebar couplers suitable for nuclear civil works applications. Only B500C rebar or stainless steel rebar to BS 6744 can be used.

Mandatory requirements are:

- Tensile strength
- Residual elongation (often referred to as slip) after tensile loading to 0.65 x characteristic yield strength of the reinforcing bar and unloading to zero load. The requirement being for a value ≤ 0.10mm or for a strain less than 0.16% or the actual strain measured on the reference bar, whichever is the greater.
- Cyclic Loading
- Effective strain

Optional requirements are:

- Compression residual elongation (slip), with the same parameters as above.

Three performance classes are detailed, with Class A being the most onerous and Class C being the least onerous.

Performance Class	Tensile Strength	Cyclic Loading	Permanent Elongation (Slip)	Effective Strain
A	▪ BS 8597 ▪ Bar Break ▪ ≥ load to produce 2% strain in ref. bar	100 cycles @ 5%-90% Re	BS 8597	≤ 140% reference bar @ 0.9Re
B	▪ BS 8597 ▪ Non bar break ▪ ≥ load to produce 2% strain in ref. bar	100 cycles @ 5%-90% Re	BS 8597	≤ 140% reference bar @ 0.9Re
C	▪ BS 8597 ▪ Non bar break	100 cycles @ 5%-90% Re	BS 8597	≤ 140% reference bar @ 0.9Re

Tensile strength tests are also conducted with specimen temperatures between -15°C and -7°C.

5.4 ETA and CE Marking

There is no harmonised European product standard for rebar coupler systems and at the time of writing there is no published European Assessment Document (EAD). In addition, rebar couplers should not be considered as being within the scope of EN 1090[7]. Therefore, they cannot be covered by a European Technical Assessment (ETA) or be CE marked.

7. EN 1090 Execution of steel structures and aluminium structures. Requirements for conformity assessment of structural components

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