Welding Reinforcing Steel

AWS D1.4/D1.4M:2011

By John Hlinka, P.E.

On a recent chemical plant project for which the author was the Engineer of Record, an electrical contractor, contrary to contract specifications, manually arc welded electrical grounding conductors to reinforcing steel for a pipe rack foundation. The electrician explained that the National Electric Code (NEC) allows welding to concrete encased reinforcing steel, and he frequently does so in lieu of independent electrical ground rods which were specified on this project. Paragraph 250.52 (A) (3) *Concrete-Encased Electrode* of the NEC does permit welding to reinforcing steel. However, NEC does not reference AWS D1.4/D1.4M *Structural Welding Code-Reinforcing Steel* or provide any guidance to the special rules, regulations, and procedures prescribed by AWS D1.4/D1.4M. If AWS D1.4 is not followed for manual arc welding reinforcing steel, the structural integrity of reinforced concrete may be jeopardized. Unfortunately, this particular contractor did not conform to D1.4 and the reinforcing steel was encased in concrete before a visual inspection could be conducted.

This article covers AWS requirements for welding reinforcing steel in reinforced concrete applications. It summarizes the main themes of the various sections as they pertain to welding reinforcing steel and contains guidelines for working with the body of rules and procedures for structural welding of reinforcing steel to reinforcing steel, welding reinforcing steel to structural steel, and welding reinforcing steel to electrical grounding electrodes. Implications to improve future projects are also addressed.

Fusion welds in shop fabrication of reinforcing steel and CADWELDs are outside the scope of this article. Electric resistance welds found in the fabrication process of welded-wire reinforcement are conducted by computer controlled welding machines within a controlled environment. A combination of pressure and heat generated by electric impulses fuse intersecting wires together. Shop personnel are never engaged in the actual welding process and no filler material or other foreign matter is introduced. CADWELDs do not apply because the steel-filled coupling sleeve of a CADWELD is a mechanical splice in which molten metal interlocks the grooves inside the sleeve with the deformations on the reinforcing bar.

Weldability of reinforcing steel and compatibility of welding procedures need to be considered and closely supervised when manual arc welding of reinforcing steel is required. Weldability is determined by the chemical composition of steel and described by the Carbon Equivalent (CE) number. Carbon is the primary hardening element in steel. Hardness and tensile strength are inversely related to ductility and weldability. As carbon content increases up to 0.85%, so does hardness and tensile strength. As carbon content decreases, ductility and weldability increases. CE is an empirical value in weight percentages, related to the combined effects of different alloying elements used in making carbon steel, of an equivalent amount of carbon. This value can be calculated using a mathematical equation. The lower the CE value the higher the weldability of the material. The welding Code provides two expressions for calculating CE. The first expression (*Equation 1*) only considers the elements carbon and manganese, and is to be used for all bars other than ASTM A706 material. A second more comprehensive equation (*Equation 2*) is given for ASTM A706 and considers carbon, manganese, copper, nickel, chromium, molybdenum, and vanadium content. Chemical composition is obtained through certified mill test reports or independent chemical analysis. Chemical composition varies for each production run, so it is important to obtain the analysis that matches the specific material to be welded. Once the CE number is calculated, the minimum preheat and interpass temperature is determined from Table 5.2 of the Code. If material test reports are unavailable and chemical composition is not known, which is particularly common in alterations and building additions of existing structures, the Code prescribes the highest preheat and interpass temperature for desired reinforcing bar size: 300° F (150° C) for number 6 bars and smaller, and 500° F (260° C) for number 7 bars and larger. If the chemical composition for ASTM A706 is not known or obtained, then preheat and interpass requirements are somewhat relaxed; no preheat is required for number 6 bars and smaller, 50° F (10° C) for number 7 to number 11 bars, and 200° F (90° C) for number 14 and larger. As with all welding, when the material is below 32° F (0° C), the Code prescribes the material to be preheated to at least 70° F (20° C), and maintained during the welding process.

$$CE = \%C + \%Mn/6 \quad (\textit{Equation 1})$$

$$CE = \%C + \%Mn/6 + \%Cu/40 + \%Ni/20 + \%Cr/10 - \%MO/50 - \%V/10 \quad (\textit{Equation 2})$$

Standard specifications for low-alloy steel ASTM A706 limit chemical composition and CE to enhance weldability. However, it is permissible to weld other base metals, such as ASTM A615, which is commonly used in reinforced concrete, as long as the appropriate weld procedure specification (WPS) is followed and correct filler weld metal is used. Many other permissible base metals are listed under paragraph 1.3.1 of the Code. High strength reinforcing steel such as ASTM A615 material is susceptible to cracking when not adequately

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Sample Material Comparison Table

Material Grade	Rebar Size	Chemical Analysis (Percent)												Preheat Temp. °F (°C)
		C	Mn	P	S	Si	Cu	Cr	Ni	Mo	Cb	V	CE	
ASTM A615	#7	0.39	1.00	0.018	0.037	0.21	0.39	0.20	0.13	0.038	0.00	0.00	0.56	200 (90)
ASTM A706	#7	0.28	1.18	0.028	0.028	0.17	0.29	0.19	0.09	0.02	0.00	0.24	0.48	50 (10)

Sample mill test report data with calculated CE numbers and minimum preheat and interpass temperatures from Table 5.2 of AWS D1.4.

preheated. Welding of ASTM A615 material should be approached with caution, since no specific provisions have been included to enhance its weldability. The *Table* compares chemical composition, CE, and preheat temperatures for sample ASTM A615 and ASTM A706 materials. As shown, the preheat requirements are lower for A706 than A615 material. A lower carbon percentage and the addition of molybdenum and vanadium contribute to a lower CE number for A706. Bar size also is considered in determination of preheat temperature. The smaller the bar size, generally, the smaller the preheat temperature. With all rebar welding, allow bars to cool naturally. Never accelerate cooling; accelerated cooling will change the metallurgy of the reinforcing steel.

Sections 2 and 3 of the Code provide allowable stresses and structural details, respectively. A wide range of details are provided, including Direct Butt Joints, Indirect Butt Joints, Lap Joints, and Interconnection of Precast Members. The effects of eccentricity should be considered when designing Lap Joints, if external restraint is not provided. AWS D1.4 does not provide details for welding reinforcing steel to electrical grounding conductors. If unavoidable, the author suggests using the CADWELD method to attach the grounding conductor to an ASTM A36 plate and then using the AWS Lap Joint detail to attach the plate to the reinforcing steel, or CADWELD the conductor directly to the reinforcing steel. Other mechanical type attachments provided by NEC are preferable to manual arc welding.

Section 4 of the Code addresses workmanship in regards to preparation of base metal, joint assembly, distortion, and quality. Welding of bars which cross and welding within two bar diameters from the points of tangency for the radius of bent bars are not permitted. Cross bar welding can lead to local embrittlement of reinforcing steel. When welding on bars that are already embedded in concrete, allowances must be made for thermal expansion of the steel to prevent spalling or cracking of concrete or destruction of the bond between the concrete and steel. Acceptable and unacceptable fillet and grove weld profiles are illustrated in Section 4 of the Code.

Section 5 of the Code discusses welding technique. Technique includes selection of filler metal, minimum preheat and interpass temperatures, welding environment, arc strikes, cleaning, progression of welding, coated base metal, and welding electrodes. Allowed welding processes include shielded metal arc welding (SMAW), gas metal arc welding (GMAW), or flux cored arc welding (FCAW). Other processes maybe used when approved by the Engineer of Record. Special storage conditions are required for low-hydrogen electrodes. Low-hydrogen electrodes must be purchased in hermetically sealed containers or must be baked prior to use. Selection of correct welding electrodes which are compatible with base metal material is critical. An incorrect choice may lead to micro cracking in the heat affected zone, which may lead to joint failure. Generally speaking, tack welds are prohibited unless they conform to all design and control requirements of D1.4. Tack welding can create a metallurgical notch effect and weaken a bar at the weld.

Sections 6 and 7 of the Code pertain to welder qualifications and inspections, respectively. All structural welding must be performed by qualified welders. WPS qualification by testing must include specific joint type and size to be welded. Inspectors must also be qualified. Acceptable qualifications include AWS certification, Canadian Welding Bureau certification, or an Engineer/Technician trained or experienced in metal fabrication, inspection, testing, and who is competent to perform inspection work. It is not unusual for the Engineer of Record to request evidence of welder qualifications prior to starting a project. Annex A of the Code includes the following sample forms for informational purposes: Procedure Qualification Record (PQR), Welding Procedure Specification (WPS), and Welder Qualification Test Record.

Conclusion

Welding of reinforcing steel should be approached with caution to prevent cracking of base metal and potentially jeopardizing the integrity of a reinforced concrete foundation or structure. AWS D1.4/D1.4M covers the design, workmanship, technique, qualification, and inspection requirements for welding reinforcing steel in most reinforced concrete applications.

NEC paragraph 250.52 (A) (3) allows welding of electrical conductors to reinforcing steel without reference to AWS D1.4/D1.4M. Electrical contractors can potentially damage the structural integrity of reinforced concrete foundations if the requirements of AWS D1.4 are not followed. Proposed Tentative Interim Amendments (TIAs) were submitted to the NFPA Standards Council on August 6, 2013. Hopefully, the NFPA Standards Council will adopt these amendments.

In the case presented at the beginning of this article, the minimum amount of reinforcing steel required by ACI 318 provided greater than two times the strength needed for design loads. Therefore, if the integrity of one reinforcing bar was reduced, the foundation would still be structurally adequate. The author suggests that a note be added to future concrete drawings that specifically prohibit welding of electrical conductors to reinforcing steel without the approval of the Engineer of Record.▪

References

AWS D1.4/D1.4M: 2011 – *Structural Welding Code – Reinforcing Steel*, 7th Edition, American Welding Society

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