Volume XVI, Number 2, 1999

Welding Innovation

Advancing Arc Welding Design and Practice Worldwide

In Good Company

We, at Lincoln Electric, certainly have a fine tradition of rewarding our employees' accomplishments. However, it is especially gratifying when one of our own is singled out for recognition by a very respected representative of the industry. Such was the case recently, when *Engineering News Record* named Lincoln's Senior Design Consultant Omer W. Blodgett one of the "Top People of the Past 125 Years," in celebration of the magazine's own 125th anniversary. In the issue dated August 30, 1999, Omer was named as a "Technology & Materials Innovator" with the following citation:

> "Before becoming the nation's preeminent author of weld-design handbooks, Blodgett beseeched highway officials to allow welded connections and plate girders in place of riveted ones. With *Design of Welded Structures* (1966), he provided necessary analytical tools. A mechanical engineer by training, and a Lincoln Electric Co. design consultant since 1945, he devised the first method for analyzing three-dimensional weld groups. In the 1980s, he rationalized the need to enlarge weld access holes to reduce cracking of welded steel jumbo sections."

Participants in our Lincoln Design Seminar Series have known for decades that as a teacher of design theory, Omer Blodgett has no peer. His observations are relevant, factual, and down-to-earth. Now, thanks to *Engineering News Record*, his achievements have been recognized as belonging in a league with those of John Roebling (1843-1903), designer of the Brooklyn Bridge; Buckminster Fuller (1895-1983), inventor of the geodesic dome; Thomas A. Edison (1847-1931); and the world-renowned architect Frank Lloyd Wright (1869-1959). In a nice bit of symmetry,

Tony Massaro and Omer Blodgett

ENR also included among its "Top 125 People" R.G. LeTourneau (1888-1964), inventor of large earthmoving equipment and founder of LeTourneau University, where the Omer W. Blodgett Endowed Chair of Welding and Materials Joining Engineering was established in 1990. All in all, pretty good company for a boy from Duluth, Minnesota, who learned to weld at the age of ten using a 200 amp Lincoln welder.

For 54 years, Lincoln Electric and thousands of our customers have had the benefit of Omer's insight, wisdom and practical know-how. While quietly going about his work of solving the most challenging design problems, he has managed to make us all look good. And now, he has made us all very proud, as well!

Tony Massaro
Chairman & CEO
The Lincoln Electric Company

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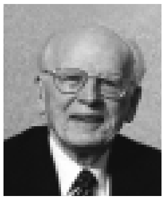

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Cover: Melbourne's Colonial Stadium features state-of-the-art technology and a retractable roof that will open and close in just 20 minutes. See story on page 22.

The serviceability of a product or structure utilizing the type of information presented herein is, and must be, the sole responsibility of the builder/user. Many variables beyond the control of The James F. Lincoln Arc Welding Foundation or The Lincoln Electric Company affect the results obtained in applying this type of information. These variables include, but are not limited to, welding procedure, plate chemistry and temperature, weldment design, fabrication methods, and service requirements.

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Common Mistakes Made in the Design of ALUMINUM WELDMENTS

By Frank G. Armao
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Background

As a rule, designers of metallic structures have learned to design using steel. When designing with aluminum, however, the engineer must not base the design on prior experiences with steel or any other material. The alloy selection, proper joint design and the choice of an optimal welding process may all be a function of the base material. While aluminum obviously obeys the same laws of mechanics as all other materials, it must be approached differently than steel when welded. Aluminum structures are not necessarily more difficult to design or weld than steel structures, they are just different.

Don't Just Choose the Strongest Alloy

Aluminum is often chosen as a structural material for applications in which weight savings are important. Very often, the designer will choose the very strongest alloy available. This is a poor design practice for several reasons. First, the critical design limitation for many structures often is deflection, not strength. In such cases, the modulus of elasticity, not the tensile properties, will govern the design. The modulus of most aluminum alloys, weak and strong alike, is approximately the same (one-third the modulus of elasticity of steel), so no benefit accrues from using the strongest alloy. Second, and most importantly, many of the strongest aluminum alloys are not weldable using conventional techniques.

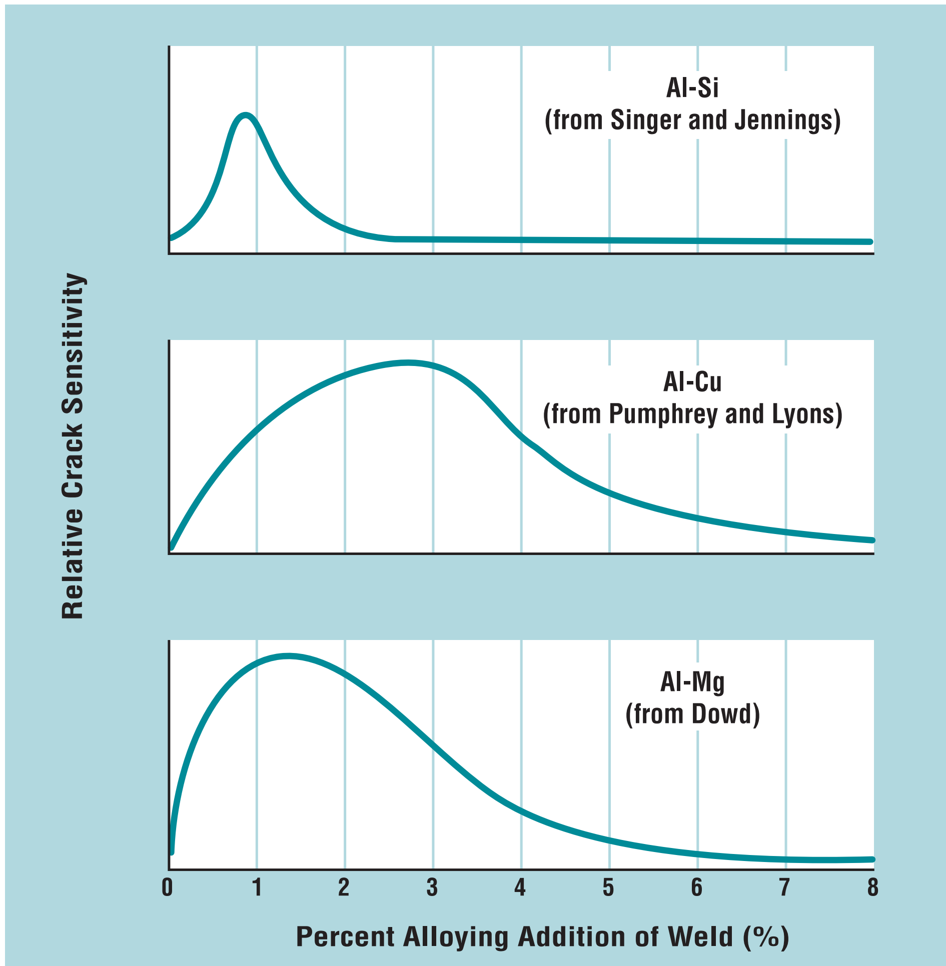

Figure 1. Relative crack sensitivity versus weld composition for various binary aluminum systems.

When we speak about aluminum alloys being "weldable" or "non-weldable," we are usually referring to the alloy's ability to be welded without hot cracking. Alloys that are extremely susceptible to hot cracking are not considered appropriate for structural (load-carrying) applications, and are generally put in the non-weldable category. Hot cracking in aluminum alloys is primarily due to the chemistry of the alloy and the weld bead. For virtually every alloying addition, the cracking sensitivity varies as alloy content increases as shown in Figure 1. Weldable alloys have a composition that falls either well above or well below the maximum cracking sensitivity. In some cases, such as that of 6061, which is very crack-sensitive if welded without filler material, the weld cracking sensitivity can be reduced to

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Alloy	Typical Ultimate Tensile Stress	
1XXX Alloys	**ksi**	**MPa**
1100-0	13	90
1350-0	11	75
1350-H18	18	125
2XXX Alloys		
2219-T62	54	370
2024-T62	64	440
3XXX Alloys		
3003-0	16	110
3003-H18	27	185
4XXX Alloys		
4143-0	17	115
5XXX Alloys		
5083-0	40	275
5052-0	25	170
6XXX Alloys		
6061-0	20	140
6061-T4	30	210
6061-T6	40	275
7XXX Alloys		
7075-T6	78	540
7178-T6	84	580

Figure 2. Various aluminum alloys and their relative strengths.

acceptable levels with the addition of a high silicon or high magnesium filler metal. The additional silicon or magnesium pushes the solidifying weld metal below the cracking sensitivity level. In other alloys, such as 7075, it is not possible to design a weld filler alloy that results in a crack-resistant chemistry. These are considered to be non-weldable.

A number of common aluminum alloys are shown in Figure 2, along with typical ultimate tensile strength values. These alloys have been broken into two groups: heat-treatable alloys and non-heat-treatable alloys. A relative assessment of weldability is also given for each of these.

The **non-heat-treatable** alloys are composed of the 1XXX, 3XXX, 4XXX, and 5XXX series. It is not possible to strengthen these alloys by heat treatment. They can only be strengthened by cold working (also called strain hardening). The 1XXX alloys, such as 1100, 1188, or 1350, are essentially pure aluminum (99+% purity). They are relatively soft and weak, with good corrosion resistance, and are usually used where high electrical conductivity is required, such as for bus bars or as electrical conductors. They are also used in certain applications that require a high degree of resistance to corrosion. All of these alloys are readily weldable.

The 3XXX series of alloys have various levels of manganese (Mn) added to strengthen them and improve their response to cold work. They are of moderate strength, have good corrosion resistance, and are readily weldable. They are used for air conditioning and refrigeration systems, non-structural building trim, and other applications.

The 4XXX series of alloys have silicon (Si) added as an alloying element to reduce the melting point and increase their fluidity in the molten state. These alloys are used for welding and brazing filler materials and for sand and die castings. They are the least crack-sensitive of all the aluminum alloys.

The 5XXX series of alloys have magnesium (Mg) added in order to increase their strength and ability to work-harden. They are generally very corrosion resistant and have the highest strengths of any of the non-heat-treatable alloys. Increasing magnesium content in these alloys results in increasing strength levels. These alloys are commonly available in the form of sheet, plate and strip, and are the most common structural aluminum alloys. They are generally not available as extruded sections, because they are expensive to extrude. They are readily weldable, in most cases, with or without filler metal. However, there is an Al-Mg cracking peak at approximately 2.5% Mg, so care must be used in welding alloys such as 5052. It should not be welded autogenously (i.e., without adding filler metal). Weld filler metal with a high Mg content, such as 5356, should be used to reduce the crack sensitivity.

The **heat-treatable** alloys are contained in the 2XXX, 6XXX, and 7XXX alloy families. The 2XXX family of alloys are high strength Al-Cu alloys used mainly for aerospace applications. In some environments, they can exhibit poor corrosion resistance. In general, most alloys in this series are considered non-weldable. A prime example of a non-weldable alloy in this series, which is attractive to designers because of its high strength, is alloy 2024. This alloy is commonly used in airframes, where it is almost always riveted. It is extremely crack-sensitive and almost impossible to weld successfully using standard techniques.

Only two common structural alloys in the 2XXX series are weldable: 2219 and 2519. Alloy 2219 is very easily weldable and has been extensively welded in fabricating the external tanks for the U.S. space shuttle. This alloy gets its good weldability because of its higher copper content, approximately 6%. A closely related alloy,

The critical design limitation for many structures often is deflection, not strength...

which is also very weldable, is 2519. It was developed for fabrication of armored vehicles. Although there are detailed exceptions to this rule, the designer should probably consider all other alloys in the 2XXX series to be non-weldable.

The 6XXX series of alloys are the alloys probably most often encountered in structural work. They are relatively strong (although not as strong as the 2XXX or 7XXX series) and have good corrosion resistance. They are most often supplied as extrusions. In fact, if the designer specifies an extrusion, it will almost certainly be supplied as a 6XXX alloy. 6XXX alloys may also be supplied as sheet, plate

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and bar, and are the most common heat treatable structural alloys. Although all alloys in this series tend to be crack-sensitive, they are all considered weldable and are, in fact, welded every day. However, the correct weld filler metal must be used to eliminate cracking. Additionally, these alloys will usually crack if they are welded either without, or with insufficient, filler metal additions.

The 7XXX alloys are the ones that usually trip designers up. They are the very high strength Al-Zn or Al-Zn-Mg-Cu alloys that are often used in aerospace fabrication, and are supplied in the form of sheet, plate, forgings, and bar, as well as extrusions. With the few exceptions noted below, the

...some alloys, often the stronger ones, are non-weldable...

designer should assume that the 7XXX alloys are non-weldable. The most common of these alloys is 7075, which should never be welded for structural applications. In addition, these alloys often suffer from poor corrosion performance in many environments.

A few of the 7XXX series defy the general rule and are weldable. These are alloys 7003 and 7005, which are often seen as extrusions, and 7039, which is most often seen as sheet or plate. Some common uses of these alloys today are bicycle frames and baseball bats, both of which are welded. These alloys are easily welded and can sometimes offer strength advantages in the as-welded condition over the 6XXX and 5XXX alloys.

There is one other exception to the general rule that 2XXX and 7XXX alloys are unweldable. There are a number of thick cast and/or wrought plate alloys designed as mold plate material for the injection molding industry. These alloys, which include Alca Plus, Alca Max, and QC-7, are all very close in chemistry to 7075 or 2618. The designer should absolutely avoid structural welds on these alloys. However, welding is often performed on these alloys to correct machining mistakes, die erosion, etc. This is acceptable because there are only low stresses on such welds and, in fact, the weld is often in compression.

This discussion has tried to make a few points:

- First, when designing a structure of any kind, don't scroll through the nearest list of aluminum alloys and pick the strongest.
- Realize that some alloys, often the stronger ones, are non-weldable. Make sure the selected alloy is readily weldable.
- Recognize that some alloys or alloy families are more suitable for some applications than others.

One more caveat: when welding aluminum, the designer must not assume that the properties of the starting material and the properties of the weld are equivalent.

Why Isn't the Weld as Strong as the Original Base Metal?

A designer of steel structures generally assumes that a weld is as strong as the parent material, and the welding engineer who is responsible for fabricating the structure expects to make a weld which is as strong as the steel being used. It would be tempting to assume that the situation is the same when designing and fabricating aluminum structures, but it isn't. In most cases, a weld in an aluminum alloy is weaker, often to a significant degree, than the alloy being welded.

In order to understand why this is so, we must discuss the heat-treatable and non-heat-treatable alloys separately and define the temper designations used for aluminum alloys.

Non-Heat-Treatable Alloys

Alloys in this category (i.e., 1XXX, 3XXX, 4XXX, and 5XXX families) are produced by a cold working process: rolling, drawing, etc. After the cold working process, the alloy is given the designation of an F temper (as-fabricated). Alloys are then often given a subsequent annealing heat treatment, after which they are classified as an O temper (annealed). Many alloys are sold in this condition. Thus the correct designation for a plate of 5083 which was annealed after rolling is 5083 – O. One of the attractive properties of these alloys is that they can be significantly increased in strength if they are cold worked after annealing. Figure 3 shows what happens to several alloys with varying amounts of cold work.

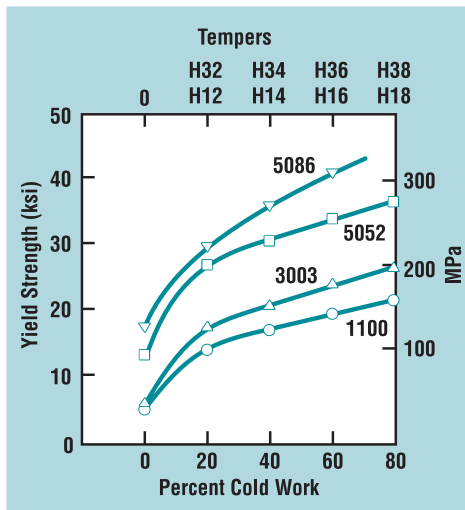

Figure 3. Effect of cold work on yield strength of several work-hardening alloys.

For example, alloy 5086 rises in yield strength from approximately 18 ksi (125 MPa) to 40 ksi (275 MPa) and is now said to be strain-hardened. A complete designation for this alloy would be 5056-H36. The H temper designation can be somewhat complicated, since it is used to designate a number of processing variables. However, the last digit, which ranges from 1 to 8, designates the level of cold working in the alloy, with 8 denoting the highest.

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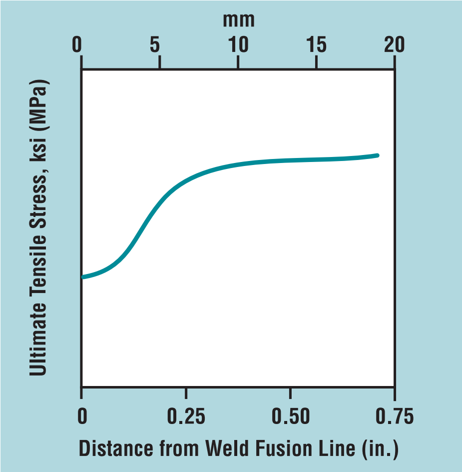

Figure 4. Tensile stress vs. distance from weld fusion line.

A common mistake in designing welded structures using non-heat-treatable alloys is to look down a list of properties, disregard the O temper material, and choose an alloy of the highest temper because it is significantly stronger. This would seem to make sense, but it often doesn't, because the heat of welding acts as a local annealing operation, significantly weakening the heat affected zone (HAZ) of the weld. If one plots the yield or tensile stress versus distance from the weld, a curve such as that seen in Figure 4 is obtained. If the design is based on the strain hardened properties, the allowable design stress will usually be above the actual yield point of the HAZ. Although it may seem counter-intuitive, the fact is this: No matter what temper one starts with, the properties in the HAZ will be those of the O temper annealed material due to the welding operation. Therefore, the design must be based on the annealed properties, not on the strain-hardened properties. Because of this, it usually doesn't make sense to buy the more expensive strain hardened tempers for welded fabrications. One should design with and specify the alloy in the O temper and upgauge as necessary.

An obvious question is whether anything can be done to restore material properties after welding a strain-hardened material. Unfortunately, the answer is almost always no. The only way to harden these materials is through mechanical deformation, and this is almost never practical for welded structures.

Heat-Treatable Alloys

The situation is somewhat different when welding the heat-treatable alloys. Alloys are heat-treated by initially heating the material to approximately 1000°F (540°C), holding the temperature for a short time, and then quenching it in water. This operation is intended to dissolve all the alloying additions in solution and hold them there at room temperature. Alloys in this condition are said to be in the T4 temper and have significantly higher strengths than the same alloy in the O temper. Depending on the alloy, "natural aging" at room temperature can lead to further strength increases over time. This takes place over a matter of days or, at most, a few weeks. After that, the properties will remain stable over decades. If one buys T4 material, it is stable and the properties will not change over the course of a lifetime.

Understanding the T4 and T6 tempers will help to overcome some of the most common mistakes...

However, most alloys are given an additional heat treatment to obtain the highest mechanical properties. This heat treatment consists of holding the material at approximately 400°F (205°C) for a few hours. During this time, the alloying additions that were dissolved in the prior heat treatment precipitate in a controlled manner, which strengthens the alloy. Material in this condition is designated as T6 (artificially aged) temper, the most common heat-treated alloy temper.

Again, the complete temper designation system is actually much more complex than this, but understanding the T4 and T6 tempers will help to overcome some of the most common mistakes made when designing aluminum weldments. It is important to note that heat treatable alloys can also be strain-hardened after heat treatment, and this can further complicate the temper designation.

Remember that the aging treatment is performed at approximately 400°F (205°C). Any arc welding process gets the HAZ much hotter than this. Therefore, welding constitutes an additional heat treatment for the HAZ. Some alloys experience an additional solution heat treatment, while other alloys become overaged in the HAZ. This results in degradation of material properties, especially if the as-welded properties are compared to T6 properties. For example, the minimum specified tensile strength in ASTM B209 for 6061 – T6 is 40 ksi (275 MPa). Most fabrication codes require a minimum as-welded tensile strength of 24 ksi (165 MPa), which is a significant degradation.

As when designing for the non-heat-treatable alloys, the designer must not use the parent material properties in design. Realistic as-welded properties must be used. It is difficult to generalize what these properties are. They change from alloy to alloy and depend strongly on the starting temper of the alloy. Most design codes contain as-welded properties for aluminum alloys and these should be used.

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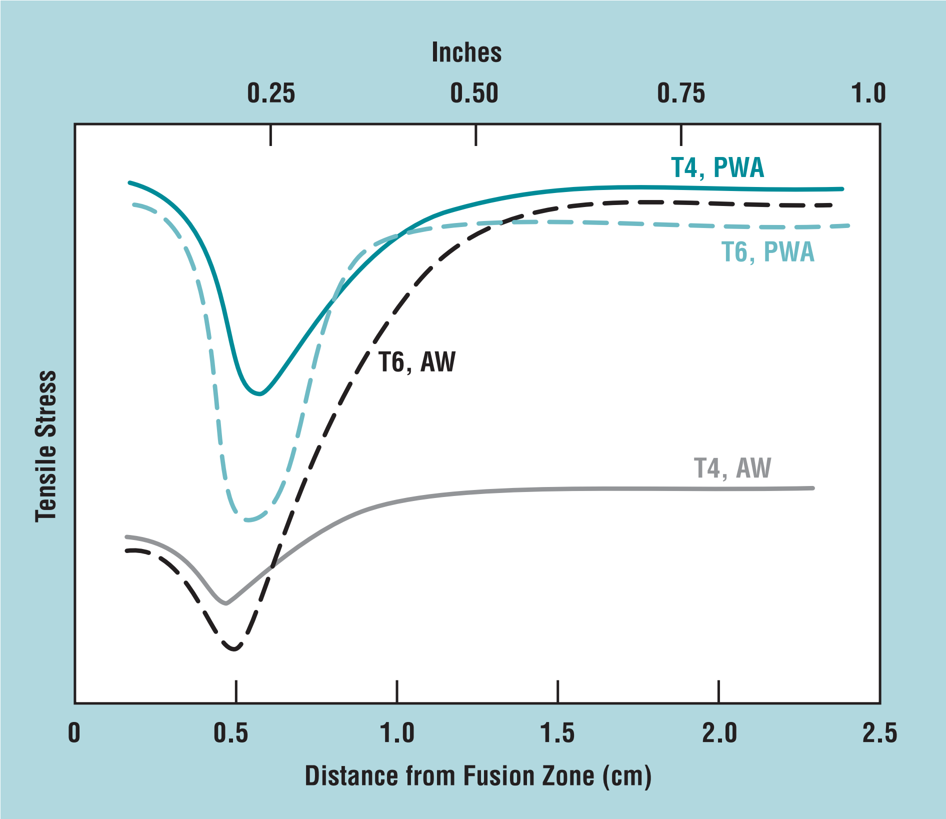

Figure 5. Tensile stress profiles of the heat affected zone for 6061-T4 and T6 starting material in the As-Welded (AW) and Post-Weld Aged (PWA) conditions.

With heat-treatable alloys, however, there are some ways to recover some of the material properties of the parent. Figure 5 shows a plot of tensile stress versus distance from the weld for 6061, revealing curves for both T4 and T6 material in both the as-welded (AW) and post-weld-aged (PWA) conditions. The PWA condition represents a weld that is subsequently aged for one hour at approximately 400°F (205°C). Post weld aging improves the mechanical properties for both T4 and T6 starting materials. In fact, often times it is better to weld in the T4 condition and post weld age after the welding process.

There is one final alternative to discuss. If after welding, the structure is given a complete heat treatment (i.e., solution treat at 1000°F [540°C], quench, age at 400°F [205°C]), all of the material properties (even in the weld) will be recovered and T6 properties will be obtained. This practice is frequently followed on small structures such as bicycle frames, but it is impractical for larger structures. Furthermore, the quenching usually causes enough distortion of the structure that a straightening operation is necessary before aging.

Conclusions

In the design of welded aluminum structures, too often the differences between steel and aluminum are not taken into account. To recap, common mistakes include:

- Not all aluminum alloys are weldable. In general, the least weldable alloys are also the strongest alloys.
- The weld will rarely be as strong as the parent material.
- The HAZ will have O temper annealed properties for non-heat-treatable alloys regardless of the initial material temper.
- For the heat treatable alloys, the as-welded properties will be significantly lower than the properties of the T6 alloy temper.
- Post-weld heat treatment can help to restore the mechanical properties of welds in heat treatable alloys.

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Framed in Steel: Dwellings for the New Millennium

By Carla Rautenberg
Welding Innovation Contributing Writer
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Cleveland, Ohio

Figure 1. This rendering of a modest traditional Habitat for Humanity house betrays no hint of the actual structure's steel frame.

At Enertech Systems, Inc., in Cleveland, Ohio, Michael Whitticar and his two partners are preaching a gospel new to the midwestern United States: the advantages of using light gauge steel in residential construction. Despite the fact that most American-produced steel comes from this region, area builders have so far been slow to embrace this alternative to wood. In the U.S., the popularity of steel-framed housing continues to be greatest in Hawaii and California, where steel's ability to withstand high winds and earthquakes has been a significant selling point, according to Geoffrey C. Stone, director of corporate programs for the North American Steel Framing Alliance (NASFA).

Whitticar notes that Enertech Systems was formed in 1994, when lumber prices had hit a peak, sparking a sudden interest in steel. Investors William Tuttle and Nicholas Russo had already identified residential construction as a huge potential market for light gauge steel. When they discovered Whitticar, a third generation carpenter who had learned how to frame houses with steel while living in Canada, they knew they had found the technical expertise needed to round out their team. For the first year of its existence, the fledgling company simply offered its services on a consulting basis. In 1995, Enertech began to get involved in the fabrication of steel trusses.

Figure 2. Prefabricated light gauge steel frame trusses were towed to the site.

Workshop Case Study

In the mid-1990s, LTV Steel approached Greater Cleveland Habitat for Humanity with an offer to donate light gauge steel, detailed drawings, some tools, and design assistance if Habitat would consent to use steel frames to construct some of its affordable homes. Agreeing with alacrity, Habitat soon secured a building in inner city Cleveland where it could panelize its own trusses. When the project reaches completion, more than 30 steel-framed Habitat houses will have been constructed in the Cleveland area.

In August, 1999, Enertech joined forces with NASFA (an affiliate of the American Iron and Steel Institute), the Lincoln Electric Company, and LTV Steel to co-sponsor a four-day "Workshop on Applications and Practices for Cold-Formed Steel Framing." The practical case for the workshop was a 1,300 sq ft steel-framed Habitat for Humanity house under construction at 2205 East 100th St. in Cleveland (Figure 1). LTV and Rysar Homes donated the time and materials to build the house, with Enertech donating some time, and also being reimbursed by LTV Steel for some of its participation.

Light gauge steel is used in 3-4 percent of homes currently being built

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An introductory seminar featured three presentations:

- Geoff Stone presented the mission and goals of NASFA.
- Hank Mailand, general manager of cost reduction for NASFA, described the organization's cost reduction program.
- Mike Whitticar lectured on "Cold-Formed Steel Framing – Applications and Practices."

Following the formal program, workshop attendees traveled to the construction site, where, after watching demonstrations by Enertech personnel, they assisted in the construction of floor joists and sheathing, exterior and interior wall framing, and the erection of roof/truss framing (Figures 2 and 3). In addition, Lincoln Electric personnel demonstrated the use of a Lincoln SP175 Plus welder and a Pro-Cut 25 plasma cutter (Figure 4).

"Fastening productivity is a critical issue for steel at this stage of its market development," says Don Moody, NASFA president. "NASFA has dedicated a great amount of effort and resources to help develop a fastening system that will connect steel members as quickly and cost-effectively as wood members are connected. Spot welding is one method we are reviewing."

Currently, Enertech uses screws to fasten light gauge steel members together. Whitticar readily admits, "We're new to the welding industry, but we certainly see the technology's potential to create a superior connection as far as providing shear value goes." He and his employees have experimented with Lincoln's new equipment for one-sided spot welding, and found it to be quick and efficient while offering a better shear value than a screwed connection. Ultimately, however, Whitticar expects welding will be fastest and therefore most cost effective for shop panelization of walls and roof trusses.

Cold Formed Steel Framing Standards Under Development

The American Society for Testing and Materials (ASTM) has announced that its Subcommittee A05.11 on Sheet Specifications is currently developing two draft standards to govern the use of steel sheet to make cold-formed framing members for studs, joists, purlins, girts and track in residential construction. According to Don Moody, president of the North American Steel Framing Alliance, "The fact that ASTM is currently developing these two important standards for cold-formed steel in residential construction is a testament to the fast-growing interest in steel for this market. NASFA strongly supports their efforts."

The draft standards now under development are:

- "Standard Specification for Steel Sheet, Carbon, Metallic and Non-Metallic Coated For Cold-Formed Framing Members"—covers coated steel sheet used in the manufacture of cold-formed framing members. Sections include terminology, classification, materials and manufacture, mechanical and coating properties, certification, chemical composition tables, and more.

- "Standard Practice for Establishing Conformance to the Minimum Expected Corrosion Characteristics of Metallic, Painted-Metallic, and Non-Metallic Coated Steel Sheet Intended for Use as Cold Formed Framing Members"—covers procedures used to establish the acceptability of metallic coated steel sheet, and painted metallic or non-metallic-coated steel sheet for use as cold-formed framing members. This practice assesses whether materials used for cold-formed framing members satisfy the required minimum expected corrosion characteristics. In-depth sections on teminology, summary of practice, use, procedure, and related topics are included.

Donald Mongeon, chairman of Subcommittee A05.11, reports: "There were people involved in the task group who use, specify, and manufacture the cold-formed framing members—specifiers, architects, engineers, steel producers. We're trying to reach compromise among those disparate interests who have their own set of priorities and we're using the ASTM balloting method to get there."

Editor's Note: Committee A-5 is one of 129 ASTM technical standards-writing committees. Organized in 1898, ASTM has more than 34,000 members from around the globe and is one of the largest voluntary standards development organizations in the world. Participation in ASTM is open to any interested party. Web Site: www.astm.org.

Potential—and Barriers

Whitticar sees the most potential for steel to penetrate the residential market with applications that are essentially a hybrid of steel and wood construction. For example, he suggests that home builders consider the use of steel floor joists for elevated floor framing because:

- Steel floor joists are dimensionally stable, which eliminates the need to cull and crown each member.
- Steel joists are lighter and will outspan traditional dimensional wood joists of equal size.
- Steel is cost-competitive with engineered wood.

Figure 3. Volunteers installed the site-fabricated steel frame.

According to NASFA, barriers to greater use of steel in residential construction include:

- The higher cost of construction.
- Thermal performance—steel alone conducts heat through the walls more than wood, but with appropriate insulation, steel can exhibit equivalent or better performance.
- Lack of infrastructure—the fact that carpenters and lumberyards are accustomed to working with wood, not steel.
- Lack of standards—although this is now being addressed by ASTM (see sidebar).

Geoff Stone notes, “At NASFA, we are systematically addressing these barriers, and our goal is to fully enable the home-building market for the widespread and economic use of steel framing, in any application that makes sense.” NASFA estimates that light gauge steel is used in one or all framing applications (floors, walls, ceilings and roofs) in approximately 3-4 percent of homes currently being built.

Commercial Use of Cold-Formed Steel

Another area that interests the principals of Enertech is the use of cold-formed steel for low-rise commercial construction, which typically includes applications such as schools, assisted care living facilities, hotels and motels, multiple occupancy residences, churches and certain types of retail structures. As an example of this market, Mike Whitticar cited his company’s work on the recently completed Eliza Bryant Center in Cleveland, which is the first HUD-financed assisted living facility to be framed in steel (Figure 5). HUD officials jumped on the light gauge steel frame bandwagon when they became convinced of the material’s benefits:

Fastening productivity is a critical issue for steel

- Non-combustible framing at a lower price than comparable fire-treated wood framing components.
- Commercial sub-trades are familiar with using steel framing.
- With the highest strength-to-weight ratio of any building material, steel is conducive to long spans.
- Attic sprinklers could be eliminated.

On September 13, 1999, the Eliza Bryant Center was officially opened. Whitticar notes that the three-story, 52,000 sq ft structure was built by combining panelization and traditional stick framing. The framing portion of the job, which consumed 212 tons of cold-formed steel, was completed in approximately 3-1/2 months, and no site crane was required.

Figure 4. The Habitat for Humanity house was used to demonstrate plasma cutting of light gauge steel.

Figure 5. Cleveland’s Eliza Bryant Center was framed in cold-formed steel.

Key Concepts in Welding Engineering

by R. Scott Funderburk

Selecting Filler Metals: Matching Strength Criteria

Introduction

This column is the first of a series that will address topics related to filler metal selection. The focus will be on the concerns of design engineers, beginning with filler metal strength. The strength of weld metal vs. base metals may be defined as matching, overmatching or undermatching. This column will address "matching" filler metal.

What is "Matching" Strength?

What is "matching strength" filler metal? The *AWS A3.0 Standard Welding Terms and Definitions* does not contain such a term, although it has been used for years. "Matching strength," on the surface, would seem to imply that the filler metal will deposit weld metal of the exact strength as (or "matching") the base metal. Codes have tables with lists of matching filler metals, such as the *AWS D1.1 Structural Welding Code – Steel*, Table 3.1, as do various filler metal suppliers. A careful review of AWS D1.1, Table 3.1, shows that the matching electrodes do not deposit welds with exactly the same strength as the base metal, and in reality, this is not what is meant by "matching."

In Table 3.1, A36 and A570 Gr. 50 are both listed in the Group I category. "Matching" filler metal is shown as both E60 and E70 electrode and flux/electrode classifications. A36 and A570 Gr. 50 have different minimum specified yield and tensile strengths, as do E60 and E70 filler metals. Obviously, matching cannot be as simple as "matching" the base metal strength (see Table 1).

While AWS D1.1 calls the preceding combinations "matching," clearly the minimum specified weld metal properties are not the same as the minimum specified base metal properties. The matching combinations for AWS D1.1, Table 3.1, Group III materials provide some additional insight, where the minimum specified filler metal properties are more closely matched to the base metal, and the tensile strength values are very similar (see Table 2).

All of the preceding examples are considered "matching," although the degree of match is different. The

Matching tensile strengths often do not result in matching yield strengths

common element is that the minimum specified tensile strength of the filler metal is always the same as or greater than the minimum specified tensile

Table 1. Filler/Base Metal Strength Comparison in AWS D1.1, Table 3.1, Group I.

Base Metal AWS D1.1, Table 3.1, Group I			"Matching" Filler Metal			
			E60, Fy = 48 ksi (330 MPa) Fu = 60 ksi (415 MPa)		**E70**, Fy = 58 ksi (400 MPa) Fu = 70 ksi (480 MPa)	
	Yield, ksi (MPa)	Tensile, ksi (MPa)	Yield	Tensile	Yield	Tensile
A36	36 min. (250)	58-80 (400-550)	Weld is 12 ksi (80 MPa) greater	Weld is between 2 ksi (15 MPa) greater to 20 ksi (135 MPa) less	Weld is 22 ksi (150 MPa) greater	Weld is between 12 ksi (80 MPa) greater to 10 ksi (70 MPa) less
A572 Gr. 50	50 min. (345)	65 min. (450)	Weld is 2 ksi (15 MPa) less	Weld is 5 ksi (35 MPa) less	Weld is 8 ksi (55 MPa) greater	Weld is 5 ksi (30 MPa) greater

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Table 2. Filler/Base Metal Strength Comparison in AWS D1.1, Table 3.1, Group III.

Base Metal AWS D1.1, Table 3.1, Group III			"Matching" Filler Metal E80, Fy = 68 ksi (470 MPa) Fu = 80 ksi (550 MPa)	
	Yield, ksi (MPa)	Tensile, ksi (MPa)	Yield Strength	Tensile Strength
A572 Gr. 65	65 min. (450)	80 min. (550)	Weld is 3 ksi (20 MPa) greater	Weld is equivalent
A913 Gr. 60	60 min. (415)	75 min. (520)	Weld is 8 ksi (55 MPa) greater	Weld is 5 ksi (30 MPa) greater

strength of the base metal. The comparison is of the "minimum specified properties," not the actual properties of the delivered steel, or of the deposited weld metal. Since these are minimum properties, actual deposited welds on the actual steel will routinely exceed those values.

Matching tensile strengths often do not result in matching yield strengths because the yield-to-tensile ratio for most hot rolled steels is lower than that of most as-deposited welds. Therefore, a match of both yield and tensile strength is improbable. However, for higher strength steels, the yield-to-tensile ratio typically approaches the values for welds and provides for a closer match of both the yield and tensile strengths. Table 3 shows the average yield-to-tensile ratio for all the base metals contained in Groups I and III and the corresponding matching filler metals of the AWS D1.1-98 Code, Table 3.1. The difference between the filler metal and base metal yield-to-tensile ratio is much less of the higher strength combination (Group III) than that of the mild steel combination (Group I) as shown by the percent difference (% Diff.).

Ultimately, matching compares weld and base metal properties. However, welds are not specified per se; filler metals are. Thus, tables of matching products typically are called "matching filler metals," not "matching weld metals."

Joints Requiring Matching Filler Metal

The need for matching filler metals is dependent upon joint type and loading condition. AWS D1.1, Table 2.3 "Allowable Stresses in Nontubular Connection Welds" shows that matching filler metal is required for only one combination of loading and joint type – tension loading of CJP groove welds, but is permitted for all other welds and loading conditions. Thus, a simple conclusion could be to always use matching filler metal. However, this may preclude better options such as undermatching combinations where cracking tendencies may be minimized. A common misuse of tables of matching filler metals occurs when other options are never considered. Particularly for high strength materials (>70 ksi [480 MPa] yield), undermatching filler metals may significantly reduce cracking tendencies.

Actual vs. Minimum Specified Properties

The traditional definition of "matching" compares minimum specified properties, not actual properties. For most applications, this has proven to be adequate, even though, based on actual properties of either the base metal or the weld, the weld may be the lower strength element. For example, A572 Gr. 50 with matching strength E70 filler metal may have matching, undermatching or overmatching relationships, based on actual properties.

A common misuse of tables of matching filler metals occurs when other options are never considered

In theory, specified service loads would be limited to some percentage of the minimum specified yield or ten-

Table 3. Varying yield-to-tensile ratios prevent matching both the yield and tensile strengths (data from AWS D1.1-98, Table 3.1).

Base Metals		Matching Filler Metals		
	Avg. Fy/Fu*	Weld	Fy/Fu*	% Diff
Group I (mild steel)	.62	E60	.80	22%
		E70	.83	25%
Group III (higher strength)	.80	E80	.85	6%

*Based on minimum specified values

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sile strength. If this were the case, the weaker component in the system would not limit the design even at the maximum design load.

This is not necessarily the case for welded components that are expected to be loaded into the inelastic range. Examples would include components in buildings subject to inelastic (plastic) deformations in large earthquakes, and roll-over protection devices on construction equipment. Under these severe loading conditions where yielding is expected, it is preferred that such deformations be distributed throughout the base metal, and therefore, the undermatching combination shown in Table 4 may be unacceptable. Further definition of matching properties as a function of the actual materials may be necessary.

For high strength materials...undermatching filler metals may reduce cracking tendencies

It is sometimes desirable to evaluate actual, or typical, properties of base metals and filler metals. For example, an electrode classified as an E70 (such as E71T-1) may also meet E80 requirements. For an application where E80 is required, the E70 product could be used, providing there is adequate assurance that the deposited weld metal will still deliver E80 properties given variability in the production of the filler metal, as well as differences in procedures.

The yield and tensile strength properties for the base and weld metal are all determined by standard tensile test coupons, uniaxially loaded, slowly strained, smooth specimens. Under different conditions of loading, and with different geometries, these mechanical properties will vary, generally resulting in higher yield and tensile strengths and reduced ductility.

Table 4. Matching (M), Undermatching (U) and Overmatching (O) tensile strength combinations for A572 Gr. 50 with E70 filler metal.

Base Metal - A572 Gr. 50		E70 Filler Metal - Strength Levels		
		Minimum 70 ksi (480 MPa)	Medium 80 ksi (550 MPa)	High 90 ksi (620 MPa)
Strength	Min. - 65 ksi (450 MPa)	M	O	O
	Med. - 80 ksi (550 MPa)	U	M	O
	High - 90 ksi (620 MPa)	U	U	M

Conclusion

Matching strength is not formally defined by AWS. However, the accepted interpretation is that the filler metal tensile strength will be equal to or greater than that of the base metal. The need for matching filler metal is dependent upon the joint type and loading condition, and it is generally required for CJP groove welds in tension applications. Matching can be used for most applications, but in some cases, it may not be the most economical or conservative choice.

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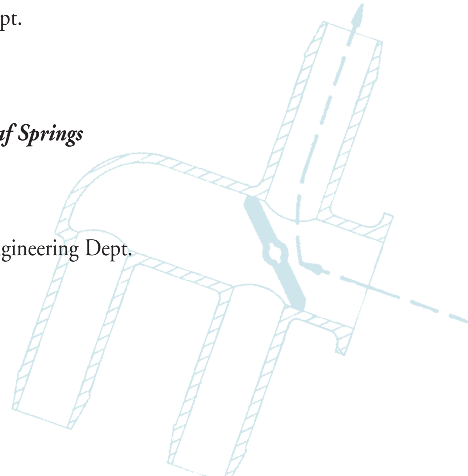

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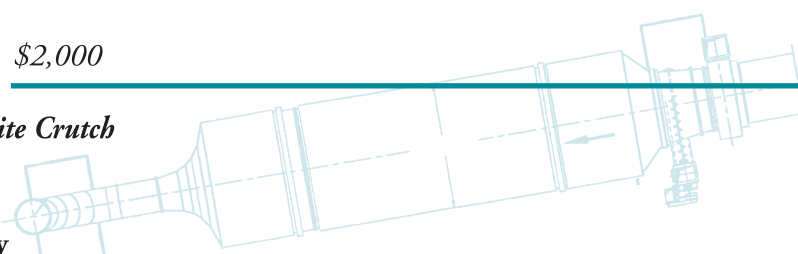

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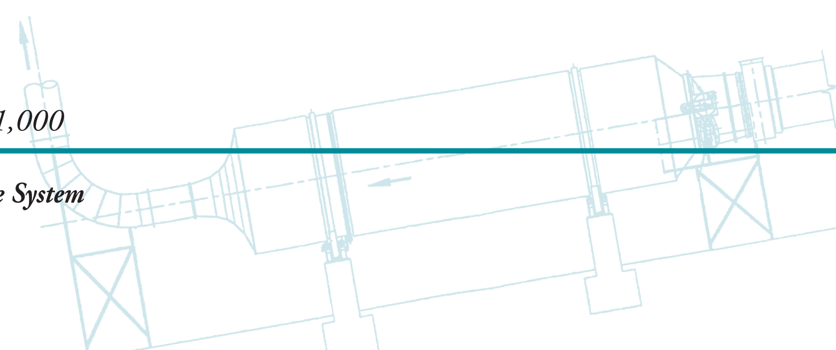

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Design File

Use Caution When Specifying "Seal Welds"

Practical Ideas for the Design Professional by Duane K. Miller, Sc.D., P.E.

Introduction

What is a "seal weld?" *AWS A3.0, Standard Welding Terms and Definitions*, defines a seal weld as: "Any weld designed primarily to provide a specific degree of tightness against leakage." The purpose of a seal weld may be to contain a fluid – either gaseous or liquid. In the mechanical and structural fields, seal welds are used most often not to prevent leakage out of a container, but to prevent entry of a fluid into a space where some type of harmful behavior, often corrosion, is expected to occur. In these fields, seal welds are frequently used to preclude moisture and oxygen-laden air and water from entering that cavity.

Seal welds may be specified on parts to be galvanized to prohibit pickling acids and/or liquid zinc from entering into a specific region. For architecturally exposed steel that is to be painted, seal welds may be specified to prevent unsightly rust bleeding. Seal welds may be required for some applications where the sealed joint is more conducive to cleanup than an exposed joint would be. Food processing facilities are one such example.

The characteristic common to all of the aforementioned examples of seal welds is as follows: none of them are placed for traditional strength-related reasons, and for this reason, caution should be exhibited when seal welds are specified. In some cases, the application of a seal weld may result in a conflict of code requirements. In others, the seal weld may perform structural functions that were unintended, resulting in undesirable load paths. Seal welds may affect inspection practices, in particular, the interpretation of ultrasonic inspection results. Finally, seal welds may be treated in a casual manner by those responsible for making them, resulting in weld quality problems. Each of these examples will be examined, as will be some issues related to galvanizing that need to be considered as well.

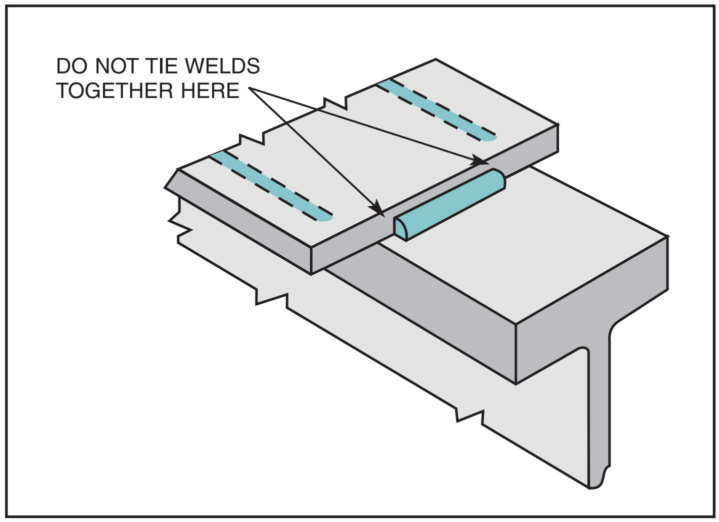

Figure 1.

Code Conflicts

A common inquiry is as follows:

> "The drawings call for seal weld, but in order for me to comply with that requirement, I need to violate *AWS D1.1-98*, Section 2.4.7.5. What should I do?"

The specific code provision cited is the one that calls for the interruption of welds which occur on opposite sides of a common plane, and under these conditions, the welds are required to be interrupted at the corner (Figure 1). This provision has a practical foundation: it is difficult to make a continuous weld in these conditions, and the probability of undercutting the corners is great when the welds are made continuous. This is one problem associated with seal welds when applied to these situations.

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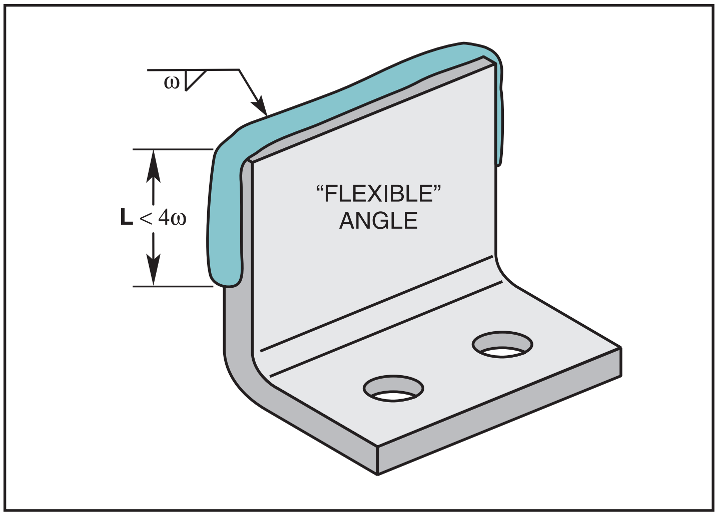

Figure 2.

Other code provisions can be violated, including *AWS D1.1*, Section 2.4.7.3, which addresses "flexible connections" that rely on the flexibility of the outstanding leg of angles (Figure 2). Examples would include framing angles, top angles of seated beam connections, and simple end plate connections. A seal weld around a flexible connection reduces such flexibility and may change the overall behavior that is expected.

AWS D1.1, Section 2.4.7.4, calls for welds on stiffeners to be cut short not less than 4 times, nor more than 6 times, the thickness of the web from the weld toe of the web-to-flange welds (Figure 3). This provision was incorporated to provide for a degree of flexibility in this region. Previous experience in shipping had shown this to be an area that was prone to cracking when the weld extended too far. Seal welds applied to this area effectively preclude such flexibility.

$4t_w \leq L \leq 6t_w$

where,

L = length of unwelded stiffener

t_w = weld thickness

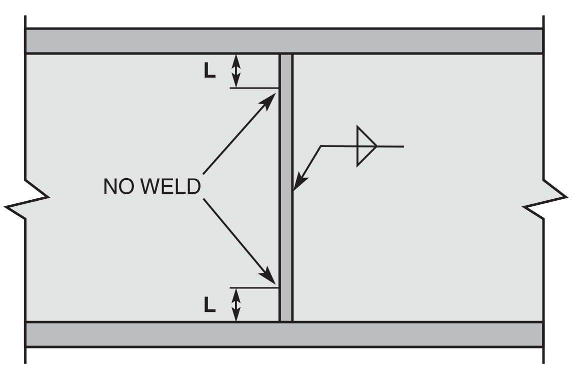

Figure 3.

The designer who calls for a seal weld should review these code provisions if the project is governed by the D1.1 code, and in the situations where the code is not applicable, examine these principles and determine their relative suitability to the components where seal welding has been utilized. To handle the issue of consistency between job specifications and code requirements, the engineer can address how these issues are to be resolved in the project specifications. The preceding list of code examples is illustrative only, and may not be comprehensive in its coverage of issues where seal welding requirements may violate code provisions.

Alternate Load Paths

The second major series of problems associated with seal welds involves those applications where unintended load paths are created. For example, a lapped connection may be joined by bolts with no welds expected at all. However, a seal weld is specified around the connection. *AWS D1.1*, Section 2.6.3, may be applicable in this situation. In bearing connections, the code does not allow bolts and welds to share the load. Of course, in this particular situation, the designer would probably not consider the seal welds as members that would share loads with welds, but in fact, they will. The seal welds would be small in size and probably incapable of transmitting the applied loads by themselves. In actual service, the first thing that would happen would be for the welds to fracture, violating the purpose of the seal weld, before the bolts would load up and carry the transferred forces.

The welding adage, "There are no secondary members in welded design," is applicable when considering seal welds. An example arose several years ago where a tub-type rock crusher had been designed with a series of stiffeners. The detailing had been carefully thought through so as to avoid stress risers. A stainless steel nameplate was to be applied to the unit, and a seal weld was called for to attach this nameplate. The entire unit received a special, multi-coat paint system to preclude corrosion, and the seal weld ensured that the material under the stainless steel nameplate would not be exposed to the elements. The nameplate was put into a high stress region, and whether

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intended or not by the designer, the nameplate became part of the load bearing system, and the weld introduced residual stresses as well.

The seal weld around the nameplate became the design-limiting fatigue detail that resulted in crack initiation in service. The intention of the designer was circumvented by an ill-conceived plan for a seal weld around a nameplate. In this particular example, any weld (including an intermittent weld) may have created a poor fatigue detail.

Casual Treatment of Seal Welds

The minimum heat input requirements imposed by *AWS D1.1* may be violated when the seal weld is made. Table 5.8 of that code prescribes certain minimum sizes of welds that must be maintained, regardless of the level of loading, in order to ensure that adequate heat input is achieved when the weld is made. The size of the seal weld may not be specified, resulting in a weld that would otherwise be disallowed by Table 5.8. It is still important that good welding practices be followed when seal welds are made, including adherence to the minimum fillet weld size. Failure to do so may result in weld cracking or incomplete fusion defects.

The welder who is charged with the responsibility of making a seal weld may approach it in a very casual manner, as might the welder's supervisor. The welder should have the same qualifications as the welder charged with the responsibility for making a similar weld that would have a structural purpose. The welding procedures, including the selection of the electrode and the required preheat level,

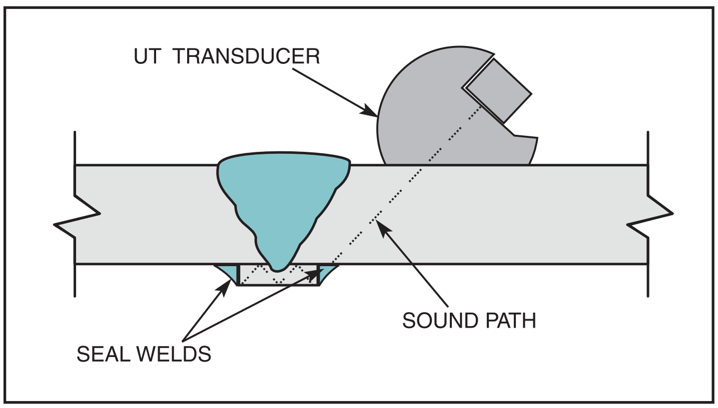

Figure 4.

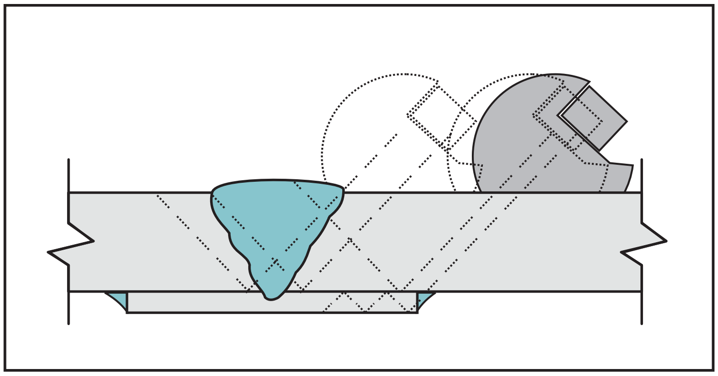

Figure 5.

are deserving of the same attention as a weld that transfers calculated loads. The claim "It is only a seal weld" is often a prescription for problems.

Inspection Issues

The presence of seal welds around steel backing that is left in place after welding may have implications for the ultrasonic testing (UT) of such connections. Consider Figure 4 in which a CJP groove weld with steel backing is inspected with UT. An alternate sound path is created when the seal welds are placed around the left-in-place backing. Such implications should be understood before inspection begins.

If backing is to be seal welded to the base material, then one may consider making the backing a little wider (Figure 5). With the seal welds further from welded joint, the UT sound waves will have a better opportunity to "see" the root without secondary reflections through the seal welds.

Galvanizing Issues

One of the more common applications for seal welds is in assemblies that are required to be hot dip galvanized (Figure 6). The American Galvanizers Association (AGA) defines three classes for welded assemblies that will be galvanized. Class 1 Joints are held together by a full seal weld. Class 2 Joints are held together by seal welds, but the overlapped area is large enough to require venting, i.e., provision of an escape hole for the release of expanding trapped gases. Class 3 Joint details do not contain seal welds.

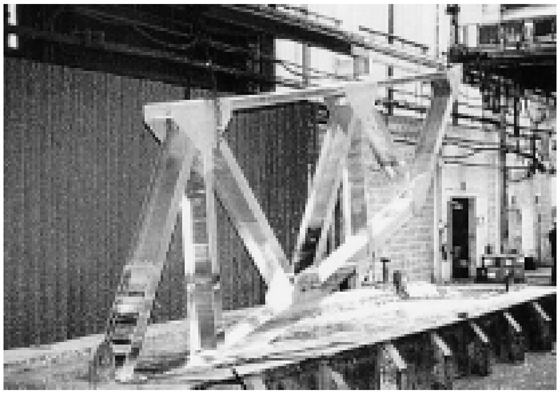

Figure 6.

Figure 7.

Figure 8.

AGA documents require a vent to be provided whenever the overlapping area exceeds 16 in^2 (100 cm^2). Specific diameters of the holes and locations are also spelled out. Thus, a Class 1 detail is only applicable for an overlapped area of 16 in^2 (100 cm^2) or less. Class 1 represents "the highest degree of corrosion protection that is attainable," and while Class 2 is "not quite equal to Class 1," it is possible to plug the vent hole after galvanizing to upgrade a Class 2 to Class 1.

Class 3 details provide "a degree of corrosion protection that meets or exceeds the protection provided by most industrial coatings." It is noted that the unsealed overlaps from Class 2 and 3 details may stain the surface of the coating, or steaming from unsealed overlaps may result in slight bare spots along the line of the exhaust.

Special caution is noted for Class 1 seal applications because porosity may result in an explosion as trapped liquid-acid vaporizes and expands when the part is dipped into the hot zinc. Venting minimizes that concern.

This edition of Design File is not intended to be a treatise on galvanizing and preferred details for corrosion resistance. However, it does identify concerns that are associated with seal welding and the galvanizing practice. The user is encouraged to review AGA documents in this regard. The American Galvanizers Association can be contacted through their website at www.galvanizeit.org, or by phone at (800) 468-7732.

Conclusions

Seal welds can perform an important function both in containing fluids, and in precluding the entry of fluids into regions where harmful effects can result. However, seal welds also can unintentionally cause differences in the structural behavior of the attached members, and the designer should be aware of these potential interactions. The welding practices employed when seal welds are made should not be any different than those associated with welds that are designed to carry loads. When seal welds are applied to galvanized assemblies, caution should be taken to make sure that venting is appropriate, and for Class 1 Joints where vents are not required, that the weld is "porosity-free" so that no seepage is experienced. Once seal welds have been carefully thought through, the designer needs to clearly communicate in the job specifications how the fabricator is to deal with code restrictions which may specify practices that are inconsistent with seal welding.

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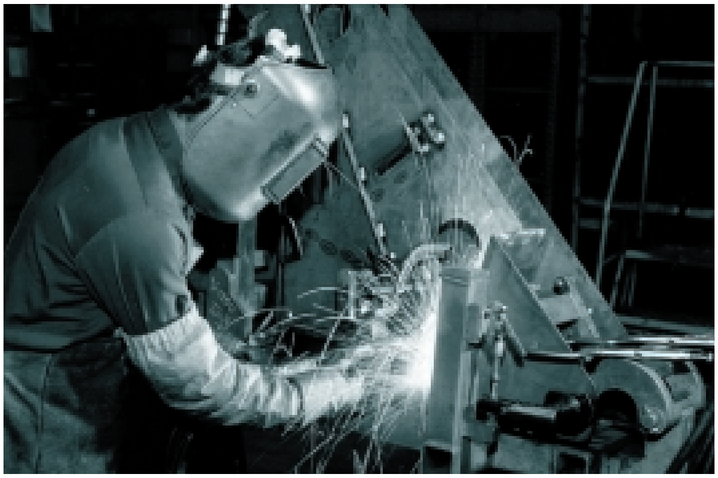
Opportunities

Lincoln Electric Professional Programs



Production Welding

Basic **May 9-11, 2000**
Advanced **September 19-21, 2000**

Each section of Production Welding is a 3-day program conducted by Lincoln Electric's staff of expert welding engineers. The Basic course includes: arc welding processes and procedures; arc blow and proper grounding; wire feeding techniques; distortion; destructive testing; safety; and more. The Advanced curriculum includes: pulse GMAW; tandem GMAW; twin and tandem SAW; aluminum welding; stainless steel welding; surface tension transfer (STT); robotic welding; waveform development; nondestructive testing; and more. 2.0 CEUs. Fee: $395.

Blodgett's Design of Steel Structures

March 7-9, 2000
October 24-26, 2000

Blodgett's Design of Steel Structures is an intensive 3-day program that addresses methods of reducing costs, improving appearance and function, and conserving material through the efficient use of welded steel in a broad range of structural applications. Seminar leaders: Omer W. Blodgett, Duane K. Miller, and R. Scott Funderburk. 2.0 CEUs. Fee: $595.

Blodgett's Design of Steel Weldments

April 11-13, 2000
September 12-14, 2000

Blodgett's Design of Steel Weldments is an intensive 3-day program for those concerned with manufacturing machine tools, construction, transportation, material handling, and agricultural equipment, as well as manufactured metal products of all types. Seminar leaders: Omer W. Blodgett, Duane K. Miller, and R. Scott Funderburk. 2.0 CEUs. Fee: $595.

NEW

Fracture & Fatigue Control in Structures: Applications of Fracture Mechanics

October 31 – November 2, 2000

Fracture mechanics has become the primary approach to analyzing and controlling brittle fractures and fatigue failures in structures. This course will focus on engineering applications using actual case studies. Guest seminar leaders: Dr. John Barsom and Dr. Stan Rolfe. 2.0 CEUs. Fee: $595.

Space is limited, so register early to avoid disappointment. For full details, visit our website at www.lincolnelectric.com/services/educate/educate.asp, call 216/383-2240, or write to Registrar, Professional Programs, The Lincoln Electric Company, 22801 Saint Clair Avenue, Cleveland, OH 44117-1199.

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Challenging Stadium Project Headed for On-time Completion

By Peter Lawlor
Southern Regional Manager
Lincoln Electric Australia
Victoria, Australia

Figure 1. Installation of a section of the retractable roof.

It was evident from the project's inception that the Colonial Stadium, currently under construction in Melbourne, Australia, would be a challenging fabrication project due to the structure's design. The stadium will feature a retractable roof that will fully open and close in just twenty minutes. Alfasi Construction was awarded the job in January 1998 by Baulderstone Hornibrook for the fabrication of the stadium's steel structure. This incorporated more than 5,000 tonnes of steelwork, including major tubular trusses with lengths up to 220 m (722 ft).

As the project progressed, several common construction issues were addressed. From this experience, the following lessons were learned:

- Materials with higher strength and alloy content are weldable, but attention to details such as hydrogen and preheat control are essential.
- Tubular construction requires extremely close fit-up and tolerance control.
- Pre-production planning and training pays big dividends.

Main Roof Chords

The steel (European EN1021O) supplied for the construction of the main roof chords is a newly developed 460 MPa (65 ksi) micro-alloyed high-strength steel for structural use. The weld fabrication required special treatment to ensure that the high strength characteristics of the steel would be fully utilized.

As Terry Phelan, general manager of Alfasi Construction explained, "I was confident of our ability to handle the fabrication of the project's steelwork. We fabricated the complex components used in Sydney's Olympic rail station and Melbourne's new Museum, so we knew what we were in for."

The higher alloy content and thicker sections of the main support beams (up to 58 mm [2.3 in]) required that close attention be paid to three main elements: the selection of the correct welding consumable; the development of realistic and reproducible welding procedures; and a focus on welder skills to ensure quality throughout. It was clear that the project schedule would not allow time for delays or rework. "In effect, we had to get it right from the very first joint," said Phelan.

Welding the main beams involved careful control of preheat and heat input...

Aware that accurate fabrication is dependent on good preparation, Alfasi purchased a Maruhide CNC controlled tube profiler. Since some of the most costly and time critical elements of tubular construction are the prepara-

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tion, fit-up and tolerances of the tubular members, this step was essential. This machine is capable of plasma cutting complex profiles in tubular members up to 12 m (39 ft) in length and with a 60 mm (2 1/2 in) wall thickness, and is the only one of its kind in South Eastern Australia. Throughout the project, this unit was used to cut and prepare complex weld profiles on most of the tubular sections.

Although there was an assortment of welded joint configurations, there were three main types of joints to be considered:

- Grade 460 MPa (65 ksi) steel to 460 MPa (65 ksi), for the main chords;
- Grade 460 MPa (65 ksi) steel to Grade 350 MPa (50 ksi) steel, for connections to the main support frame; and
- Grade 350 MPa (50 ksi) to Grade 350 MPa (50 ksi) steel, for general connections and supports.

Matching the Weld Metal Properties

The governing code for the construction of the beams was AS1554 Part 1. However, the higher alloy content of the steel (carbon equivalent of 0.63-0.68) meant the construction specification required further clarification to ensure optimum strength and quality were achieved. For instance, care was taken to ensure weld metal properties closely matched the parent plate and weldments returned heat affected zone hardness of less than 300HV.

The governing code recommended that HAZ hardness values be kept below 350 HV

In order to meet the high strength properties of the tubular steel (minimum specified yield strength of 460 MPa [65 ksi] and minimum ultimate tensile strength of 560 MPa [80 ksi]), as well as meet the minimum specified Charpy V-Notch impact properties, while maintaining low hydrogen values, an E81T1-Ni1 (Outershield 81Ni1-H) gas shielded flux cored electrode was used to join the main chords. Straight lengths were joined by a submerged arc combination of F7A6-EM14K-H8 (LA71 electrode with 880M flux).

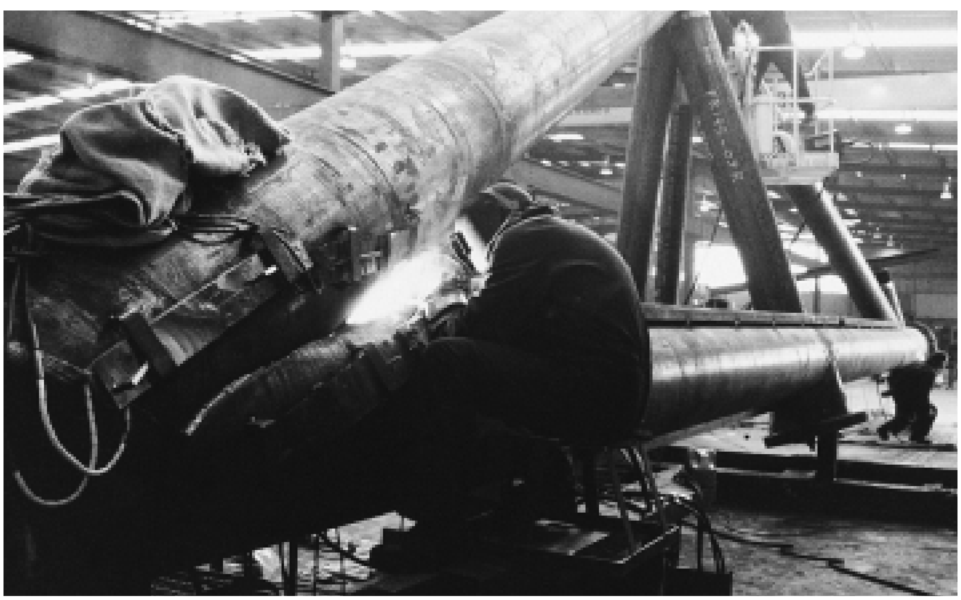

Figure 2. Shop fabrication of some of the large tubular trusses used in the Colonial Stadium.

Initial weld tests indicated that the 460 MPa (65 ksi) steel was prone to high heat-affected zone hardness if preheat and welding heat input requirements were not followed. To ensure that operators were aware of the importance of these factors, additional training was provided to the construction crew to explain the correct handling of the steel and the importance of following the proper welding protocol. The minimum preheat temperature for each joint (varied between 125°C [250°F] and 225°C [440°F] depending on the specific joint details) was maintained and monitored using electric heat blankets. It was this pre-production planning and training that enabled the construction to move along at such an efficient pace.

Achieving Desired Mechanical Properties

Welding the main beams involved careful control of preheat and heat input to achieve good mechanical properties. The welding of the high strength 460 MPa (65 ksi) steel to 350 MPa (50 ksi) steel created a few problems.

As Merril Degee, workshop foreman of Alfasi's Dandenong facility explained, "The welding of the 460 to 460 joints was relatively straight-forward once we determined the effect of preheat and heat input on joint strength and hardness values." However, providing for elasticity and a smooth transition of strengths between the 460 MPa and 350 grade material wasn't so easy. "When I first went to do a procedure for a 'T' type joint made up of a Grade

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350 vertical plate with a 460 cap, I used a standard E71T-1 electrode, which did not meet the bend test acceptance criteria. Therefore, it was determined that a different electrode was required."

An electrode with a controlled hydrogen content was selected for these joints (Outershield 71C-H) to meet the testing criteria. The electrode, which meets the E71T-1 classification, was designed to meet 5 ml (max) of hydrogen per 100 grams of weld metal. The new welding procedure with OS71C-H and careful bead placement gave excellent results. The moderate yield and tensile strength of the weld metal gave a smooth transition between the Grade 350 steel and the high strength Grade 460 steel.

The new welding procedure with Outershield 71C-H and careful bead placement gave excellent results

"The end result was a joint with good flexibility, strength and low hydrogen contents. The welders liked using the electrode. For joining the Grade 350 steel we used a GMAW ER70S-4 electrode (L54) and an FCAW-g E71T-1 electrode (Outershield 71M). Currently, (the project is 85% complete) we're a little ahead of schedule. It's obvious now that without the early focus on welding processes, procedures and electrode selection we wouldn't be in this position," said Degee.

Over 5,000 tonnes of steel have been processed so far, using more than 6 tonnes of electrode with very few weld defects.

Construction Logistics

Given the considerable size of some of the weldments, distortion was a potential problem. However, with careful fixture building and continuous monitoring of dimensions during fabrication, distortion was kept to a minimum. The main chords were fabricated in Alfasi's Dandenong workshop in lengths up to 40 m (130 ft), then transported to the site where they were joined using field welding procedures.

Engine driven welders and portable wire feeders were used to complete the final field welds on the main trusses. Small site tents were erected to ensure that preheat and gas shielding would not be affected by the elements.

For joining the Grade 350 steel to itself, an all-position E71T-8J self-shielding electrode (Innershield NR203MP) was used.

Conclusion

Terry Phelan summed up the current status of the Colonial Stadium as follows: "We've just passed a landmark project date on schedule. Most of the steelwork has been fabricated and it's now a matter of lifting and fixing sections into place. It's a tight schedule, but we're meeting it thanks to dedicated staff and the support of major suppliers. You need that type of partnership when the pressure is on."

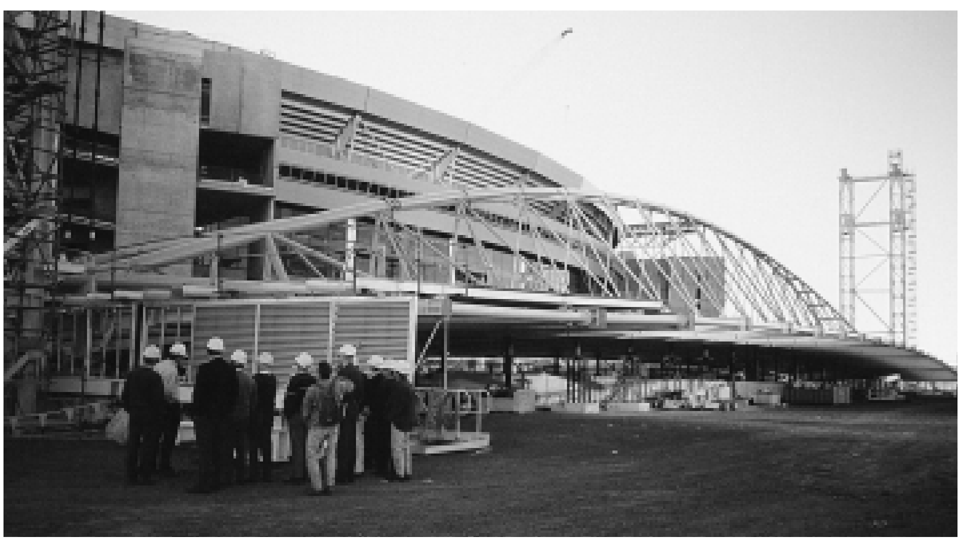

Figure 3. After field welding, a tubular truss awaits installation as part of the retractable roof assembly.

Editor's Note: The A$460 million (US$293 million) stadium is scheduled to be completed by February 2000. It will have 52,000 fixed seats, plus retractable seating on the lower tier that will allow the stadium to be reconfigured to suit a wide variety of needs. It will be primarily a venue for Australian Football League (soccer) games and other sporting events. However, an advanced acoustic design and audio system will make it suitable for music concerts as well. Selected seats will be equipped with individual touchscreen video units. More information on the stadium can be obtained online at www.docklandstadium.com.au.

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P.O. Box 17035
Cleveland, Ohio 44117-0035

The
James F. Lincoln
Arc Welding
Foundation

Volunteers erected the steel frame for this Habitat for Humanity house in less than three days. *See story on page 7.*

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