Volume XIX, Number 2 , 2002

Welding Innovation

Advancing Arc Welding Design and Practice Worldwide

A publication of the James F. Lincoln Arc Welding Foundation

Technology and Change

That technology provides the impetus for change is no surprise. Western civilization has made exponential progress through the past two millennia because of significant developments in technology. The driving force for change though, more now than at any other time in history, is the scientific method and then subjecting the results from the use of the scientific method to applications in the real world. If the tested technology proves to be externally valid – repeatable and robust away from the laboratory environment, then there will be an expected increase in the use of the newer method.

During the past one hundred years, the world of welding has made great technological strides: power source design evolved from power grids, motor generators, and transformer rectifiers to today's software driven inverter transformers. Such is the state of welding power sources today, that their energy-efficient transformer design and malleable software based output provide unequalled arc performance.

The software-driven inverter transformer continues to enhance the state of gas metal arc welding to the point where the process limits for GMAW are being challenged – and the results are nothing short of spectacular. Lower spatter, lower weld fumes, lower hydrogen weld deposits, and improved finished weld quality are the essential features of the newer technology, and they all work together to provide lower welding cost. More importantly, welding process development has effectively widened the window of opportunity to apply GMAW: both thinner and thicker sections of a wide range of base material types are effectively joined in accordance with governing welding codes. The newer technology is promoting change because the newer methods are externally valid – they are repeatable and robust.

Central to the change process for gas metal arc welding, and any other welding process in this technocentric era, is the successful transfer of newer technology to the end-user. The precise transfer of information is fundamental to successful implementation of technology, and these two facets of change carefully intertwine for successful implementation.

Jean Piaget, in his theory of cognitive development, identifies three elements central to the learning process: *assimilation, accommodation*, and *equilibration*. The extrapolation of Piaget's theory meshes well with the transfer of technology, and consequently, it serves as an appropriate paradigm for fostering change.

Assimilation of the new technology:
- Language should be clear and concise – no jargon.
- The documentation for the new technology must support its features, advantages, and benefits.
- Examples and graphics should support the benefits of the new technology.
- Potential pitfalls ought to be clearly defined.

Accommodation of the new technology:
- This is where the comparison and contrast occurs and change begins to take place.
- Testing of the newer technology takes form here and the benefits of the technology are measured against older methods, ideas, or tools.
- The quantified results are either externally valid or the new technology is disgarded.
- If the technology is acceptable, then the stage is set for the next phase.

Equilibration of the new technology:
- During this final phase, implementation of the new technology occurs.
- There is no conflict between the benefit of the new technology and existing methods.
- The new technology either replaces or dovetails with the older technology.
- The system is balanced.

In this issue, we are featuring new technology that has brought about positive changes in welding processes, welded design, and fabrication materials. We think that the presentations will permit you the opportunity to assimilate technology in the form of ideas, concepts, and tools. All of them are innovative, and each introduces creative and well reasoned departures from what was formerly known to be true. We invite you to investigate the technology presented here and more importantly, we encourage you to begin to *accommodate* the technology that we wish to transfer!

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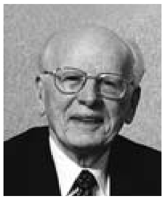
Welding INNOVATION

Cover: A close-up of Amie Laird McNeel's sculpture "Gaze" shows the importance of welding to her work. Story on page 19.



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Volume XIX
Number 2, 2002

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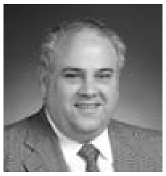

Design & Fabrication of Aluminum Automobiles

By Frank G. Armao
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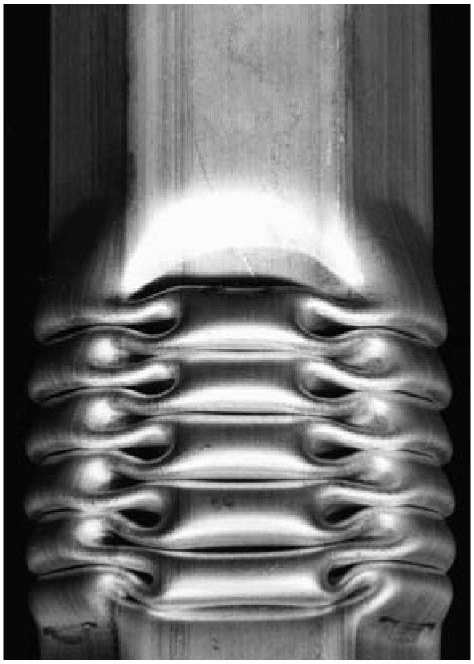

Figure 1. Aluminum front frame rail crushed in crash test showing uniform crushing and energy absorption.

History

Aluminum was first isolated in 1888 as an element. It rapidly gained in application as people learned how to alloy it to improve its mechanical properties. By the mid-1920s, Pierce Arrow had begun to make at least one model of its cars entirely from aluminum. While all-aluminum cars have appeared periodically over the years, the use of aluminum has never become widespread in the automotive industry. However, in the last ten to fifteen years, the use of aluminum in automobiles has increased dramatically. In fact, the average aluminum content of automobiles increased 113% between 1991 and 2000. Today, the average car contains over 250 lbs. (113 kg) of aluminum alloys.

Over the years, some very well-known cars have been built entirely from aluminum. These include:
- The Mercedes-Benz 300SL Gullwing in the 1950s
- The Shelby AC Cobra in the 1960s
- The Jaguar D type
- The Ford GT40

In the more recent past, the fabrication of high-end automobiles from aluminum has continued with:
- The Acura NSX
- The Aston Martin Vanquish
- The Audi A8
- The BMW Z8
- The Ferrari 360 Modena
- The Mercedes CL coupe
- The Plymouth Prowler
- The Shelby Series 1
- The new Ford GT40

All of these cars are made using either a monocoque body structure (in which the covering absorbs a large part of the stresses to which the body is subjected) or a space frame made entirely from aluminum. Therefore, it should be fairly obvious that it is possible to obtain very good structural performance from aluminum. However, all of the models listed above are made at relatively low volumes (20,000 per year maximum). Is it possible to manufacture aluminum vehicles at higher volumes? In fact, Audi has taken a large step by making the Audi A2 completely from aluminum alloys at a volume of 80,000 per year in Europe.

Aside from the all-aluminum car, there is increasing use of aluminum in outer body panels (i.e., fenders, hoods, decklids) in virtually every manufacturer's model lines. Most bumper beams today are made from aluminum alloys. Perhaps even more noteworthy from a structural standpoint, there are increasing volumes of aluminum engine cradles (the Chevrolet Impala and Malibu and the 2002 Nissan Altima) and rear suspension cradles (the Chrysler Concorde, the Dodge Intrepid, and the BMW 5 Series). The fact that these are being made at volumes as high as 700,000 per year goes a long way toward proving the viability of high volume, all-aluminum automobiles. As we will see below, welding is a major contributor to making this possible.

Why Aluminum?

Aluminum has a number of properties that make it attractive for application in automobiles. However, it has one characteristic that overrides all others: its light weight. Aluminum automotive alloys are one third as dense as steels, while many of them have tensile and yield strengths almost equal

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to those of construction grade steels. Does this mean that we can make aluminum parts that weigh one third of steel parts? In general, no. Most parts of a car are not strength-limited, but are stiffness-limited. (There are exceptions to this – the areas around the shock towers are usually strength-limited). Because stiffness is a function of Young's modulus, which is 10 x 10^{b}psi (68,950 MPa) for aluminum alloys and 30 x 10^{b}psi (206,850 MPa) for steels, weight reductions of 2/3 are not usually possible. Weight reductions of 40%–45% are more typical.

The U.S. Federal Government publishes Corporate Average Fuel Economy (CAFE) standards. These standards dictate the fuel economy levels that every auto maker must meet. Failure to meet them can result in penalties. Car manufacturers are under a great deal of pressure to increase fuel economy across the board. One of the easiest ways to do this is to reduce the weight of the automobile. Reducing the total weight of the car by 10% normally results in an 8%–10% improvement in fuel economy. Even something as simple a substitution of an aluminum hood for a steel one has a significant effect on average fuel economy.

Aluminum has another advantage over steel. It can be easily extruded, while steel can't. This allows the designer to create complex shapes of varying wall thickness using extruded sections. Internal stiffening ribs can be integrally extruded, so that cross sections consisting of multi-hollows are routinely used. The only closed section tubing available in steels is simple shapes such as rounds, squares, ovals, etc. This has allowed designers of aluminum auto structures to venture into automotive space frames and hybrid structures, instead of using only the monocoque sheet construction used in steel automobiles.

But what happens in a crash? Won't an aluminum car just crumple into a ball of aluminum foil? The answer is an emphatic "No!" For a detailed discussion of the behavior of aluminum automotive structures in crash tests, the interested reader is referred to "Automotive Aluminum Crash Energy Management Manual," publication AT5, published by the Aluminum Association in Washington D.C. For our purposes, it is sufficient to say that it is not difficult at all to make aluminum automobiles that meet or exceed the NHTSA crash test requirements set out in FMVSS 208, which is the same criterion steel cars must meet. Innovations in alloys and processing have resulted in materials that crush uniformly and absorb energy better than steels. Figure 1 shows an actual front crash rail from a production car. It has begun to crush and has buckled in a controlled, uniform manner, absorbing crash energy and ending up about half as long as it started. Good designs and improved materials are the keys to superior crash performance.

> **Aluminum can be easily extruded, while steel can't**

Space Frames versus Sheet Cars

Until approximately thirty years ago, cars were made as an assembly of a sheet metal body and a heavier, separate chassis. The body provided little, if any, structural strength and was assembled by resistance spot welding (RSW) and bolting. The frame, made from thicker members, was assembled primarily by arc welding, rivetting, and bolting.

Then, in the late 1960s and early 1970s, automotive design changed. The so-called "unibody" was born. In this construction method, the entire body, except for the hang-on panels, is part of the car's structure and contributes to the car's stiffness and strength. There is no separate frame, although small front or rear subframes may be used to hold the engine, suspension, etc. These cars are made almost exclusively of steel sheet of various thicknesses which is stamped and joined together by RSW. In 2002, the car makers have seventy plus years of experience in RSW and are very good at it. All of the infrastructure to support RSW is in place.

Why not just make aluminum cars by up-gauging the material thickness from steel to aluminum and assemble them by RSW? Indeed, that's possible and one of the major aluminum companies supports this strategy, using a combination of RSW and adhesive bonding. However, this approach often results in extra costs.

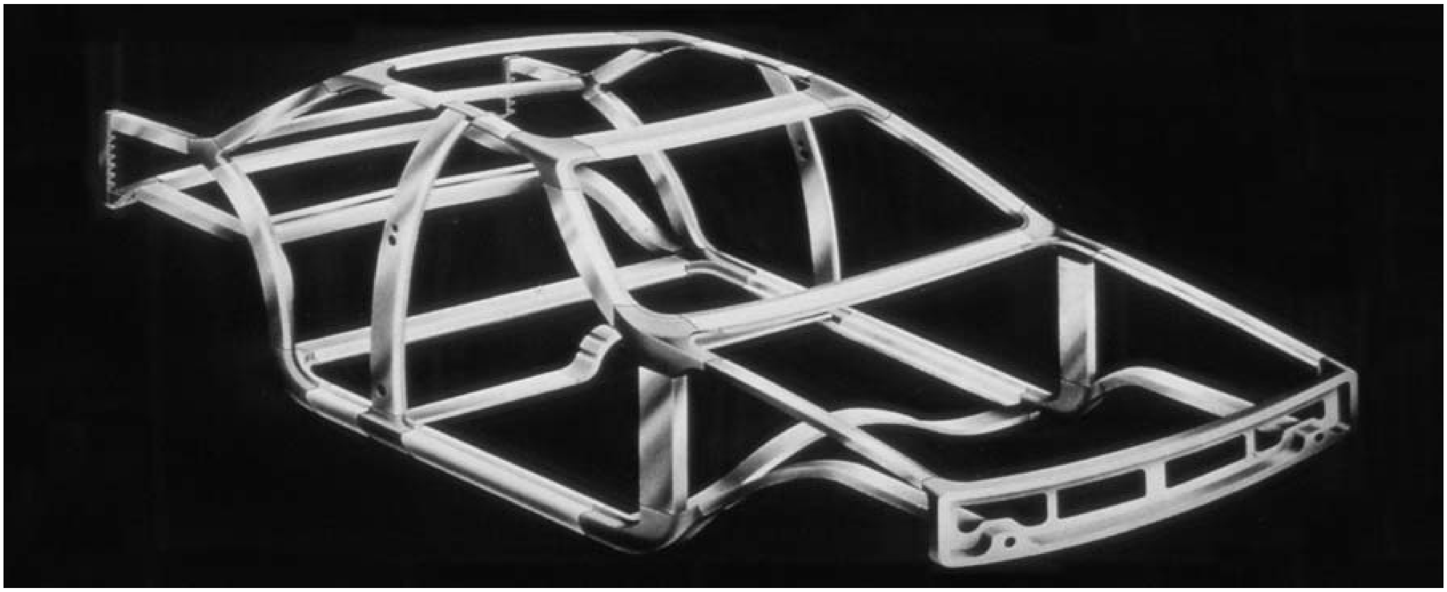

Figure 2. The Audi A8 spaceframe.

For production volumes under 100,000 per year, it has been shown that either a pure space frame or a hybrid space frame/sheet approach is more cost effective. This results mostly from the fact that extrusion dies are relatively inexpensive, while stamping dies are much more costly.

Figure 2 shows a photograph of an Audi A8 space frame. This method of construction employs "nodes" which are made from castings, formed sheet or extrusions. Each node serves as a joining point for several structural members. The nodes are designed so that there is at least one slip plane for each joint. This serves to minimize gaps between the node and the structural member coming into it. While it is possible to use other joining methods, such as adhesive bonding, most of the existing aluminum space frame cars, including the Audi A8 and A2, the Ferrari 360, the Ford GT40, the BMW Z8, and the Shelby Series 1, are arc welded. The Audi A8 space frame contains 70 m (approximately 230 ft.) of gas metal arc welding. Only the Aston Martin Vanquish is adhesively bonded and riveted.

Why Gas Metal Arc Welding?

If automakers go to aluminum vehicles, why not just spot weld them together as they do now on steel vehicles? There are a number of reasons.

RSW of aluminum presents some unique challenges. The aluminum readily alloys with the copper spot welding tips, so electrode life can be very short. The electrical conductivity of aluminum is much higher than that of steel, so not as much resistance heating takes place at the interface of the two pieces to be joined. Consequently, currents required for RSW are often three times what they are for steel, so the equipment used for steel seldom can be used for aluminum.

There are 17 pulsing variables that can be programmed

Because of these issues, many automakers have moved away from RSW for aluminum. For joining aluminum sheet parts, many have gone to self-piercing riveting, often in combinations with adhesives. However, for joining extrusions and/or castings, these processes have some limitations:

- Only lap joints are possible. Tee or butt joints cannot be made.
- Physical access to both sides of the joint is required.
- When joining castings or extrusions, it is usually necessary to add a flange in order to make the joint. This adds back some of the weight that has been saved.

GMAW is not without limitations either. When joining thin sheet, welding distortion is sometimes excessive. The heat of the welding arc softens the HAZ of the joint, reducing mechanical properties. However, GMAW has a number of advantages that have made it the preferred method for joining of castings, extrusions, and thicker sheet (thicker than 0.070 in. or 1.8 mm), as follows

- It is usable for all types of joints – lap, tee, and butt.
- It is easily automated using robotics
- Access to only one side of the joint is required.
- It is fairly tolerant of part misalignment and joint gaps.
- Capital equipment costs are low.
- It is a well-established, widely used process.

GMAW Technology Development

On the surface, gas metal arc welding (GMAW) might appear to be an older, low tech process. It is anything but. Even ten years ago, it would have been very difficult, if not impossible, to GMAW aluminum members as thin as 0.040 in. (1 mm) thick. Today, welding thin aluminum is fairly easy and the

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development of GMAW has become an enabling technology for the use of aluminum in automotive fabrication.

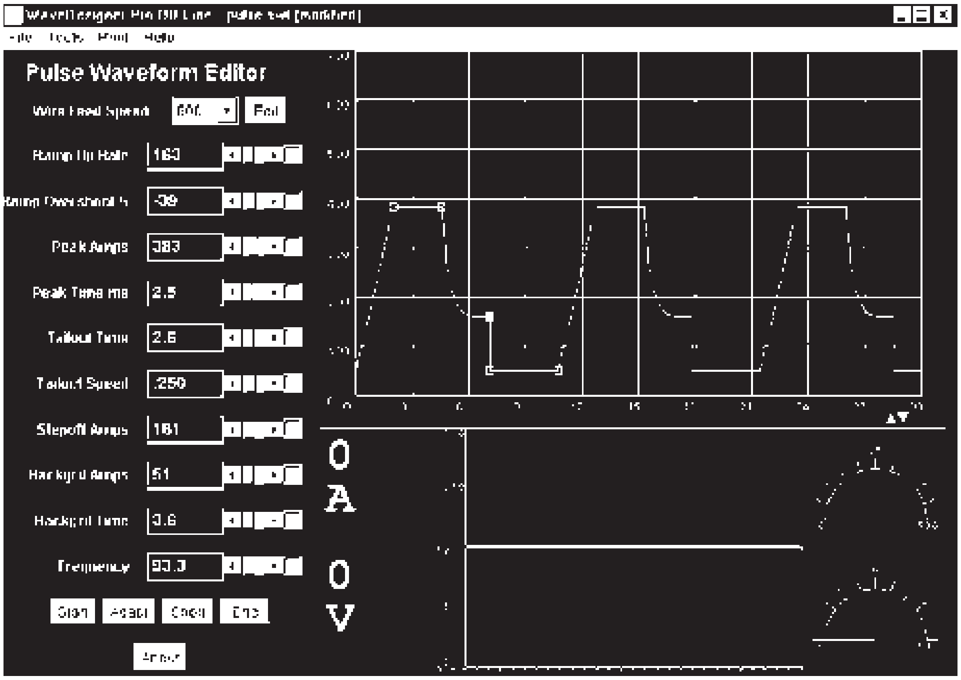
GMAW of thin aluminum was complicated by the fact that short circuiting arc transfer (short arc) is not recommended for GMAW of aluminum alloys. When gas metal arc welding steels to weld thin material, the welder uses a finer welding wire and keeps going lower in current and deeper into short arc transfer. However, if this approach is used on aluminum, incomplete fusion defects occur. Short circuiting arc transfer is never recommended for aluminum because of this.

Spray transfer is always recommended for welding aluminum. In years past, it was impossible to weld thin aluminum, say, of 1/16 in. thickness (1.6 mm), because even with the smallest diameter aluminum wire available for GMAW, 0.030 in. (0.8mm), the welding current had to be above 85 amperes to get spray transfer. This was just too much current to weld thin materials, so GMAW of thin aluminum simply was not performed in production.

However, electronics technology developed and made it possible to control the welding process much more precisely and to change the welding current very quickly. Pulsed GMAW was developed. In fact, it was developed over twenty years ago. However, it is very different today than it was then.

Pulsed GMAW has proved to be especially applicable to welding of thin aluminum. Fundamentally, the welding current is pulsed between a high peak current where spray transfer is obtained and a low background current where no metal is transferred across the arc. This means that we have spray transfer, but the average welding current is much lower. So now we can weld aluminum as thin as 0.020 in. (0.5 mm) and we can have spray transfer at average currents as low as 30 amperes or so, even with larger diameter 0.047 in. (1.2 mm) wires.

Early pulsed GMAW power supplies were transformer controlled and limited to 60 or 120 Hertz pulsing frequencies. Today's power supplies are inverter based, software controlled, and programmable. Control frequencies are often 20 KHz. This flexibility has allowed a tremendous amount of GMAW process development.



Pulse Waveform Editor

Wire Feed Speed 600
Ramp Up Rate 163
Ramp Overshoot % -39
Peak Amps 383
Peak Time ms 2.5
Tailout Time 2.6
Tailout Speed .250
Stepoff Amps 181
Backgrd Amps 51
Backgrd Time 3.6
Frequency 93.3

Figure 3. Software screen used for programming Lincoln pulsing power supplies.

Figure 4. Multi–process programmable welding system.

Figure 3 shows a computer screen of proprietary software used for programming pulsed GMAW in a contemporary power supply. There are seventeen pulsing variables that can be programmed. The programmer chooses a wire feed speed (WFS) and develops the optimum pulsing variables for that WFS and saves them. This process is repeated over the range of wire feed speeds and the data is saved as a program.

This whole process is invisible to the user, who merely picks a WFS. The power supply then automatically sets all of the pulsing variables. The only other control is a "Trim" control that gives the welder control over arc length. All the welder has to do is pick a program number and a WFS to have access to a program that is optimized for pulsing for the specific filler alloy and wire diameter being used. Furthermore, if the specific application is so unique that the standard program is inadequate, it can easily be reprogrammed by the manufacturer or, in some cases, by the user.

Figure 4 shows a photo of one such power supply. This power supply can be combined with a push-pull welding torch. Using such a welding system,

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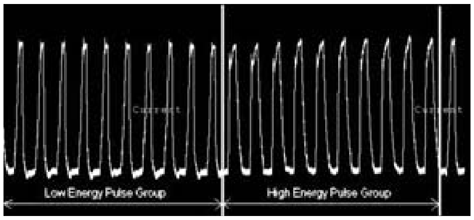

Figure 5. Schematic of Pulse On Pulse waveform.

aluminum wires as fine as 0.030 in. (0.8 mm) can be fed as far as 50 ft. (15 m).

However, GMAW technology development still has not stopped, or even slowed down. The tremendous capabilities available today to control and switch the welding process are stimulating continuing development. For instance, a recent development is a control pulsing logic for thin aluminum called "Pulse On Pulse." This waveshape is shown schematically in Figure 5. In this process, a number of relatively high energy pulses are alternated with the same number of low energy pulses, causing a weld ripple to be formed each time the low energy pulses fire, and resulting in a very uniform weld bead. An example of Pulse On Pulse welding is shown in Figure 6. This type of pulsing has shown itself to be very applicable to automotive fabrication and is in use already in such applications.

The Future

As in all areas of life, the future is hard to predict. Is there an all-aluminum car in your future? This depends on a lot of factors. If the Federal government increases CAFE requirements, it will drive automakers to reduce vehicle weight further. If aluminum ingot prices stay low, additional aluminum use is more likely. However, ingot prices have been volatile in the past, and that scares auto manufacturers. Whatever the future, though, there is likely to be greater use of aluminum in cars. That means that some of us will continue to try to improve gas metal arc welding technology.

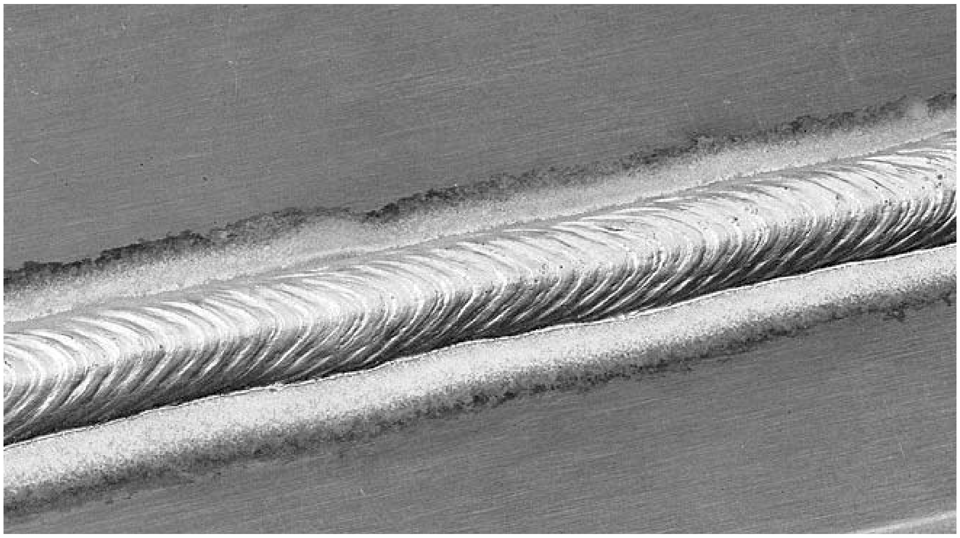

Figure 6. A weld in 3 mm aluminum made using Pulse On Pulse welding.

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Lincoln Electric Technical Programs

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Submerged Arc Welding, **October 7-8, 2002**
Gas Metal Arc Welding, **October 9-10, 2002**
Each program will provide the basic theoretical concepts that support the process, advanced topics, and new developments. Both programs will emphasize welding process optimization and welding cost reduction opportunities. These seminars are designed to benefit welding engineers, technicians, supervisors, instructors, quality assurance personnel, and manufacturing engineers.
Fee: $375 each, or $595 for both.

Welding of Aluminum Alloys, Theory and Practice

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Space is limited, so register early to avoid disappointment. For full details, see

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Or call 216/383-2240, or write to Registrar, Professional Programs, The Lincoln Electric Company, 22801 St. Clair Avenue, Cleveland, OH 44117-1199.

Design File

Mixing Welds and Bolts, Part 2

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

In a previous edition of *Welding Innovation* (Volume XVIII, Number 2, 2001), Part 1 of "Mixing Welds and Bolts" was published. That column dealt with snug-tightened and pretensioned mechanical fasteners, including rivets, combined with welds, as well as existing specification requirements for such combinations. Part 1 can be obtained by downloading a PDF file from the *Welding Innovation* web site at www.weldinginnovation.com. Part 2 will address combining welds with slip-critical, high-strength bolted connections, and will also examine existing specification provisions for various combinations of welds and bolts in light of recent research.

Review of Part 1

In Part 1, general information was provided on bolted connections. Snug-tightened, pretensioned, and slip-critical bolted connections were defined. ASTM A325 and A490 bolts were identified, and the capacity of rivets identified as typically about half of the strength of A325 bolts. Slip-critical joints have bolts that have been installed in a manner so that the bolts are under significant tensile load with the plates under compressive load. They have faying surfaces that have been prepared to provide a calculable resistance against slippage. Slip-critical joints work by friction: the pretension forces create clamping forces and the friction between the faying surfaces work together to resist slippage of the joint. The basic design philosophy relies on friction to resist nominal service loads. The provisions for design of slip-critical connections are intended to provide 90–95% reliability against slip at service load levels. In its strength limit state, slip can occur and the bolts will go into bearing. This should not be the case for service loads.

The focus of this Design File series is not upon bolted connections, but rather upon connections that are composed of both welds and bolts. For the snug-tightened and pretensioned bolted connections, it was shown that welds cannot be assumed to be capable of sharing loads with the mechanical fasteners. *AWS D1.1 Structural Welding Code-Steel* and *AISC LRFD Steel Specification* require that the welds be designed to carry the entire load under these conditions. The Canadian standard *CAN/CSA-S16.1-01* provides a more rational criterion by permitting load sharing between welds and bolts for service loads, providing the higher of the two capacities can carry all factored loads alone.

Part 2 focuses on slip-critical joints, combined with welds. As mentioned in Part 1, this topic is the subject of ongoing research and consideration by the various technical committees. Much of this work has been done by Drs. G. Kulak and G. Grondin and their co-workers of the University of Alberta, Canada, and definitive conclusions have not yet been reached as to how these findings should be incorporated into US standards, such as *AWS D1.1* and *AISC LRFD*. However, at least some parts of current standards are likely to be determined to be unconservative, and practicing engineers should review these data and determine how specific projects should be addressed in light of these findings. The same research has drawn into question some of the current specification requirements for snug-tightened connections when welds are added, and these findings will be reviewed.

Code Provisions for Slip-Critical Connections with Welds

The issue of mixing mechanical fasteners and welds is addressed in *AWS D1.1: 2002 Structural Welding Code–Steel*. Provision 2.6.7 states:

> "Connections that are welded to one member and bolted or riveted to the other shall be allowed. However, rivets and bolts used in bearing connections shall not be considered as sharing the load in combination with welds in a common faying surface. Welds in such connections shall be adequate to carry the entire load in the connection. High-strength bolts installed to the requirements for slip-critical connections prior to welding may be considered as sharing the stress in the welds. (See:

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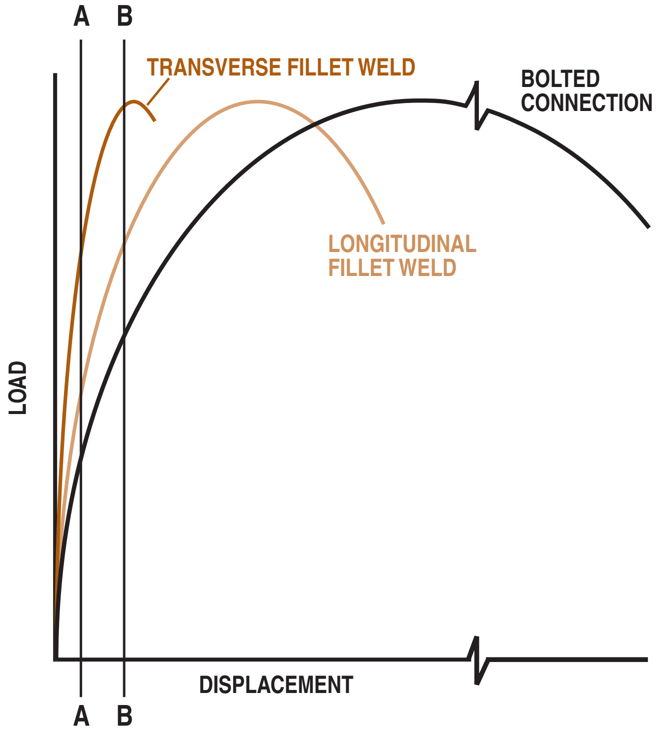

Figure 1.

Specifications for Structural Joints Using ASTM A325 or A490 Bolts of the Research Council on Structural Connections.)"

Note: Part 1 cited the 2000 version of D1.1, in which these provisions were contained in 2.6.3. The latest version is largely unchanged in concept, although the underlined words in 2.6.7 are new for the 2002 edition.

The fourth sentence deals with slip-critical connections. Notice that, in order for sharing to be considered, this provision requires that the high-strength bolts be installed "prior to welding." More will be said on this issue later. *AISC LRFD – 1999*, Provision J 1.9, expresses the same general philosophy when it states:

> "In slip-critical connections, high-strength bolts are permitted to be considered as sharing the load with the welds."

The commentary to this provision provides some additional understanding of both the AISC and AWS provisions:

> "For high-strength bolts in slip-critical connections to share the load with welds it is advisable to fully tension the bolts before the weld is made. If the weld is placed first, angular distortion from the heat of the weld might prevent the faying action required for the development of the slip-critical force. When bolts are fully tensioned before the weld is made, the slip-critical bolts and the weld may be assumed to share the load on a common-shear plane. The heat of welding near bolts will not alter the mechanical properties of the bolts."

The straightforward reading of these provisions, and indeed the intent of them, is to permit the direct combination of the capacity of the slip-critical connection and the weld. However, recent research indicates that this is not the case, and such an assumption may be unconservative.

The commentary that addresses the angular distortion explains the apparent justification for requiring that the bolts be installed before welding. The basis for such a requirement is suspect, however. Kulak and Grondin point out that "slip resistance of the bolted joint is independent of the amount of area between faying surfaces. As long as there is some area, which is a physical necessity for proper preloading of the bolts…, then the slip resistance will be developed." (Kulak and Grondin, from the minutes of the AISC TC6 Connections Task Committee, June 12-13, 2002.) Thus, the apparent justification for the sequential requirement may be suspect.

Different Deformation Capabilities

In Part 1, the differences in the deformation capabilities between welded connections and those joined with bolts in either a snug-tightened or pretensioned manner was identified as the factor that precluded the simple arithmetic addition of the capacities of the two systems. The welds were identified as being "stiff," whereas the snug-tightened or pretensioned bolted connection could slip to distribute the applied loads on the mechanically fastened joint.

The concept presented in codes with respect to slip-critical connections was presumably based upon the lack of slip in the connection (that is, their "stiffness"), justifying the assumption that the capacities of the two types of joining systems (welds and bolts) can be joined. Ultimately, a slip-critical bolted connection will slip, but if a weld is added, such a connection cannot slip. Thus, the capacities of the two elements cannot be combined in terms of the ultimate strength capacity.

Figure 1 contains a conceptual plot of the load/displacement relationships for welds and bolts. Note that the load/deformation relationships are different for each of the three elements. It should be noted that the two types of welds shown are not equally "stiff." The actual curve for the bolted connection is illustrative only; in fact, there would be various curves for the different types of bolted connections.

Additionally, while in this illustration the three curves are all shown having the same strength, under most conditions, the capacity of each element will be different. The differences in stiffness preclude simple mathematical additions of the various capacities.

Figure 2 illustrates six possible connection details: a) bolts only, b) longitudinal fillets only, c) transverse fillets only, d) bolts and transverse fillets, e) bolts and longitudinal fillets, and f) bolts with both longitudinal and transverse fillets. In this illustration, it is assumed that the strength of the connections in Figure 2a-2c is equal, as is illustrated in Figure 1. The bolts, for example, offer the same load resistance, as do the transverse fillet welds. All the bolts shown in Figure 2 are assumed to be slip-critical.

If the code provisions cited above were correct, that is, if the capacities of welds and slip-critical bolts could be mathematically combined, then the connections with bolts and welds in Figure 2d and 2e would both be twice the value of the connections in Figure 2a-2c. Further, if these provisions were correct, the capacity of Figure 2f would be three times that of Figure 2a-2c. Loads, however, are not evenly split between the various elements in the mixed connection, because of the differences in the load/deformation curves.

Referring again to Figure 1, the bolted connection in Figure 2a would have a load/deformation curve like the bolt curve. For a unit strength of 1, the deformation experienced would also be a unit of 1. For the longitudinal fillet in Figure 2b, the strength is also normalized to a value of 1, but the deformation capacity is estimated to be 1/6 of the bolted connection. The transverse fillet of Figure 2c also has strength of 1, but with a deformation capacity of about one sixth of the longitudinal fillet weld.

To analyze the combination of welds and bolts and their ultimate load capability, constant displacements for each element must be considered, and the resistances to deformation for each element added to determine the total capacity of the combination. Consider the combination of longitudinal fillet and bolts (Figure 2e). Line A in Figure 1 illustrates a likely deformation level that would contribute to the total connection strength of a level 1. However, rather than a 50-50 split, the weld contributes about 60% of the strength, with 40% coming from the bolts. At line B where the weld is capable of delivering 100% of its strength, the bolts can contribute only about 80% of theirs, and the combination is not 200%, but rather about 180%, or 10% less. Of course, the code provisions would suggest 200%, the direct addition of both members.

The same exercise could be performed with bolts and transverse welds. The reduced deformation capacity of the transverse fillet makes the differences even more

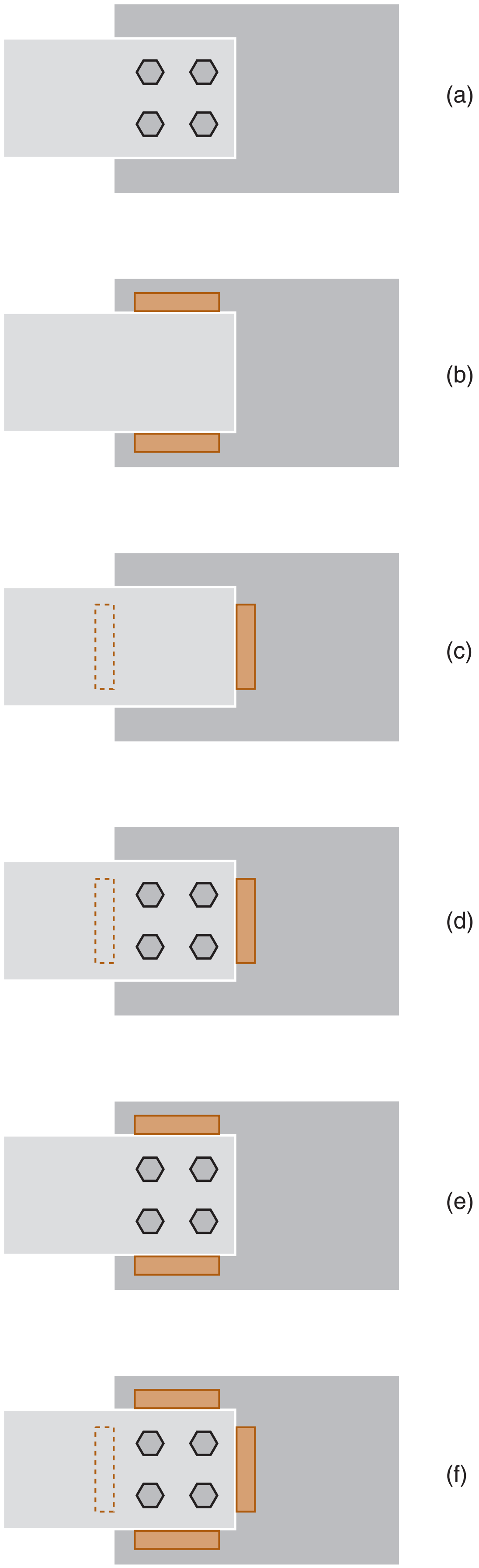

Figure 2.

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pronounced. Thus, the significance of these differences in displacement is more pronounced for the connections composed of bolts and transverse welds.

A Proposed Model

Kulak and Grondin propose a model whereby the ultimate load resistance of the joint can be computed from the following relationship:

$$R_{utl\ joint} = R_{friction} + R_{bolts} + R_{trans} + R_{long}$$

Where $R_{friction}$ is the frictional resistance
R_{bolts} is the bolt shear resistance
R_{trans} is the transverse weld shear resistance
R_{long} is the longitudinal weld shear resistance

$R_{friction}$ is estimated to be 0.25 times the slip resistance of the slip-critical bolted joint. For slip-critical connections in conjunction with welds, this factor is always present, but is accounted for differently, depending on the orientation of the weld (longitudinal versus transverse). This factor, of course, would be zero for bearing-type bolted connections.

R_{bolts} depends on the type of weld (transverse or longitudinal) and the condition of bearing, whether already in bearing (positive) or unknown (indeterminate).

For transverse welds along with slip-critical bolted joints, the ultimate joint resistance is the strength of the transverse weld plus the frictional resistance, or the bolt shear, whichever is greater.

For longitudinal welds along with slip-critical bolted joints, the ultimate joint resistance is a percentage of the bolt shear plus the shear resistance of the longitudinal weld plus the frictional resistance, or the bolt shear, whichever is greater. Under positive bearing conditions, 75% of the ultimate bolt shear strength is used, and for indeterminate bearing conditions, 50% is used.

The work of Kulak and Grondin indicates that for slip-critical connections, the code provisions are unconservative. For example, the capacity of a combined longitudinal weld and bolts is equal to the weld capacity plus 50% of the bolt capacity. For this condition AWS and AISC would indicate the weld capacity plus 100% of the bolts capacity, thus overestimating the capacity of the connections.

Recall from Part 1 that in the general case, AWS and AISC require that combinations of welds and bolts of the bearing type be designed such that the entire load is transferred through the weld. Thus, regardless of the capacity of the bolts, any small weld addition effectively eliminates the capacity of the bolts. The preceding model could be used to address these snug-tightened connections. In such cases, $R_{friction}$ is zero. The greater capacity of the bolts and welds could then be used, as is the case in the Canadian standard *CAN/CSA-S16.1-01*. The Kulak work would indicate that this approach is correct and conservative.

The Kulak work has also revealed new information regarding the combination of longitudinal and transverse fillet welds, which are subject to some of the same deformation capacity differences. This will be addressed in a future edition of Design File.

Conclusion

The responsible technical committees are evaluating these research findings, and changes to specifications will no doubt result. Currently, the data suggest that while a portion of the slip-critical bolt capacities can be directly added to the capacities of longitudinal welds, the same is not the case for slip-critical bolts and transverse welds. In the case of the latter, the greater capacity of the two elements is a conservative assumption.

Acknowledgements

A sincere thanks to all of my professional colleagues who generously gave of their time to review and critique the content of this article.

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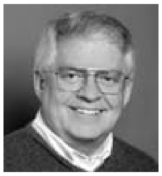

Technology Transfer

Contributed by Jeff Nadzam, Group Leader, GMAW and GTAW
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Cleveland, Ohio

Tandem GMAW: The Flexibility of Pulsed Spray Transfer

Suitable advances in technology foster change, and the changes that we are witnessing in the welding industry today are due to the forces of new power source technology. Moreover, it is no accident that much recent research and development work focuses on gas metal arc welding (GMAW). Historically, the bridge and structural fabrication industries have tended to view GMAW with derision, and with some cause. Issues regarding incomplete fusion set a precedent that has seriously limited the implementation of GMAW in code quality applications. However, recent advances in GMAW power source technology allow an opportunity to challenge conservative thinking regarding the use of gas metal arc welding.

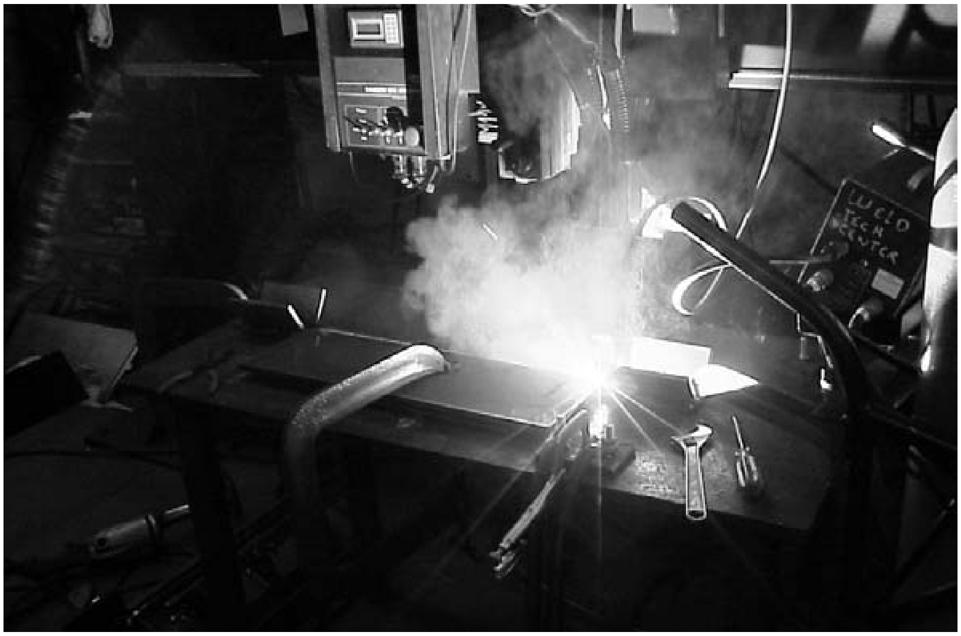

Figure 1. Welding ASTM 516 grade 70 base material test plates with tandem GMAW.

GMAW Process Review

Gas metal arc welding, by definition, is a process that produces coalescence of metals by heating them with an arc between a continuously fed filler metal electrode and the work. The process uses shielding from an externally supplied gas to protect the molten weld pool. The application of GMAW requires DC+ (reverse) polarity to the electrode.

In gas metal arc welding there are four traditional modes of metal transfer:

- Axial spray transfer is the higher energy mode and it provides the benefit of excellent fusion, but it is restricted to the flat and horizontal positions. Spatter is absent and the penetration profile is uniform.
- Pulsed spray metal transfer (GMAW-P) is a higher technology mode of metal transfer that provides the benefits of axial spray, but at a lower average current. The pulse exceeds the transition to spray transfer for a very short period, then it is reduced to a lower energy level often associated with short circuit transfer. Metal transfer only occurs during the pulse peak. This mode of metal transfer was developed because of its ability to lower spatter levels, overcome incomplete fusion defects, and be implemented in out-of-position welding applications.

Pulsed spray metal transfer provides the benefits of axial spray at a lower average current

- Globular metal transfer is historically associated with the use of 100% carbon dioxide shielding. The molten metal transfer occurs non-axially in droplets that are one and a half to three times larger than the diameter of the electrode. Globular transfer usually results in higher spatter levels, and it is prone to incomplete fusion.
- Short-circuit transfer is the low heat input mode of GMAW, in which metal transfer occurs as a result of physical contact between the elec-

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Wire Feed Speed (inch / min) 400

Advanced Variables

Ramp up rate 800

Ramp overshoot -10

Peak Current 420

Peak Time 1.2

Tailout time 1.5

Tailout Speed .225

Step off Current 60

Background Current 60

Background Time 3.0

Frequency 175.4

Adaptive ● Adapt ○ No_Adapt

Amp Sec 1.20

Figure 2. Software employed to manipulate the pulsed spray mode of metal transfer. Note the nine pulsed spray transfer waveform components: Ramp Up Rate, Ramp Overshoot, Peak Current, Peak Time, Tailout Time, Tailout Speed, Step-off Current, Background Current, Background Time, and Frequency.

trode and the weld pool. This mode of metal transfer historically excels in the joining of sheet metal thickness material or open root pipe welding. When applied to a base material thicker than 3/16 in. (5 mm), short-circuit transfer can result in incomplete fusion.

New Developments

The transformation of GMAW, led by the development of software-driven inverters, has earned a second chance for critical code quality applications. Leading the way is the pulsed spray mode of metal transfer employed with Tandem GMAW (Figure 1). The newer features of the process invite several opportunities to reduce the manufacturing costs associated with both light and heavy steel fabrication. Consider the following:

- The arc can be tailored for penetration profile, heat input, and mechanical properties.

- The use of tandem GMAW, which incorporates two independent pulsed arcs in the same weld pool, leads to higher deposition rates and higher electrode efficiencies than was previously possible.

- GMAW produces lower levels of hydrogen and the process lends itself to a cost-effective alternative for joining high performance and high strength low alloy steels.

- Weld bead appearance is excellent.

- GMAW produces low levels of welding fumes, which can be an advantage for shop or other indoor fabrication.

The Tailorable Arc

Essential to the development or the manipulation of a particular welding waveform is an understanding of the relationship of the electrode type, its diameter, and the shielding gas employed. Shielding gas is central to determining the outcome of the finished weld and it has a profound effect upon penetration profile, bead shape, toe wetting, and mechanical properties. For example, the arc characteristics of a 95% argon + 5 % oxygen blend may be suitable for high travel speed welding on sheet metal thickness, but the penetration profile may be undesirable for plate thickness material. The electrode diameter, whether it is solid or metal cored, has an associated maximum current carrying capability. A 0.045 in. diameter (1.1 mm) electrode reaches its maximum current at approximately 420 Amps, and the maximum for a 0.035 in. diameter (0.9 mm) is approximately 220 Amperes.

The deposition rate is associated with a specific useable current range and, quite naturally, the higher the current the more energy there is to apply to the weld joint. For example, a solid 0.045 in. (1.1 mm) diameter electrode can carry more welding current than a 0.035 in. diameter (0.9 mm) electrode. Given similar wire feed speeds and arc travel speeds, we would expect that the penetration into the base material would be greater for the larger diameter than the smaller. Similarly, it would be true that the deposition rate potential would be higher for the larger diameter electrode. Selecting the electrode diameter and the shielding gas then becomes a choice based upon the needs of the joint, the base material type and thickness, the required mechanical properties, and through-put.

Advancing technology has produced astounding improvements in GMAW-P

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Figure 3. The tandem torch permits the delivery of two electrodes: the lead arc and the trail arc. The nozzle provides uniform shielding gas coverage for the molten weld pool.

Both bridge and structural fabricators could take advantage of the tandem GMAW process

It is true, then, that each welding application carries specific user-defined requirements for the finished weld. Because the new technology permits modification to the components of the GMAW-P waveform, these weld requirements may be more readily achieved.

Nine components are associated with the pulsed spray waveform (see Figure 2). Each component in combination with the others provides specific attributes to the finished weld. The energy level and appearance of the arc change with the manipulation of each of the components. For example, high pulsed frequency produces a narrow arc that may lend itself to use on flare-bevel type weld joints. Increasing the peak current results in an increase in energy associated with deeper weld penetration, and the opposite is also true. The use of higher front ramp rates stiffens the arc and thus increases the immunity of the arc to arc blow conditions.

Pulsed GMAW waveforms for the tandem GMAW process include a wide range of electrode diameters, from 0.030 in. to 1/16 in. (0.08 mm to 1.6 mm) and material types. Shielding gas selections include argon and carbon dioxide or argon and oxygen combinations. Ternary, three-part shielding gas blends are rarely employed. Tandem GMAW typically uses electrodes of the same diameter, but in some instances the diameter of the trail electrode may be smaller. The judgement about when to employ differing diameters generally follows a case-by-case evaluation.

Tandem GMAW

Tandem GMAW is a welding process that uses two DC electrode positive (DC+) arcs in the same weld pool, and they are identified as the *'Lead'* and the *'Trail'* arcs (Figure 3). Each arc uses its own power source and wire drive, and the possible combinations of modes of metal transfer employed in tandem GMAW are as follows:

- Axial Spray Transfer Lead Arc + Axial Spray Transfer Trail Arc
- Axial Spray Transfer Lead Arc + Pulsed Spray Transfer Trail Arc
- Pulsed Spray Transfer Lead Arc + Pulsed Spray Transfer Trail Arc

The lead arc, in all cases, determines the penetration level of the weld, and the trail arc provides the final bead shape and weld bead reinforcement. The programs that are created for tandem GMAW, particularly in the case of the Pulse + Pulse, are developed with DC+ arc compatibility in mind.

The development of tandem GMAW had higher arc travel speed as its core objective, and it is generally used with material the thickness of sheet metal. The travel speed on sheet metal applications is usually 1.5 to 1.9 times the travel speed for a single arc, and it is not uncommon to find travel speeds of more than 100 ipm (2.5 m/min).

For thicker sections of material where multiple pass welding is necessary, the deposition rate for tandem GMAW can vary from 20–45 lbs/hr (9–21 kg/hr). The arc travel speeds range from 25–45 ipm (0.6–1.2 m/min). To achieve anticipated mechanical properties, tandem GMAW may require the use of special welding techniques.

Testing Tandem GMAW

Two ASTM A516 grade 70 test plates were assembled, welded, and tested to the requirements of ANSI/AASHTO/AWS D1.5-96 “Bridge Welding Code,” Section A. The welding procedure involved the use of two 0.052 in. (1.4 mm) diameter ER70S-6 electrodes in tandem, and the shielding gas employed was a 90% argon + 10

Table 1. Results of mechanical testing for each of 2 ASTM A516 grade 70 test plates.

Mechanical Properties	Test Plate #1	Test Plate #2
Tensile Strength	90,000 psi (620 Mpa)	89,600 psi (617 Mpa)
Yield Strength	73,300 psi (505 Mpa)	73,300 psi (505 Mpa)
Avg. Ft.-Lbs. @ -20° F	76	78
Avg. Joules @ -29° C	103	106

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% carbon dioxide. Both the lead arc and the trail arc employed the pulsed spray mode of metal transfer. The effective deposition rate for the test was 32 lbs/hr (14.5 kg/hr). The results of the mechanical testing, for each of the two plates, were as shown in Table 1.

Discussion of Results

The results indicate that tandem GMAW using pulsed spray transfer with 0.052 in. (1.4 mm) diameter electrodes is viable for complete penetration weld joints in structural fabrication. In addition, it would be fair to assume that both bridge and structural fabricators could take advantage of the tandem GMAW process not only for complete penetration groove welds, but also for completing fillet welding on stiffeners. Moreover, it would appear that the use of robotic or specialized hard automation would in many cases provide both the motion and process control necessary to implement tandem GMAW.

Conclusion

Advancing technology permits the use of GMAW-P on a wide range of welding applications, including thicker section base materials. The use of tandem GMAW for depositing high quality weld metal with excellent fusion represents the culmination of several years of application research and development. The optimized arc condition permits the use of two DC+ pulsed arcs in the same molten puddle. Moreover, it represents a reasonable alternative for welding components of bridges and other structures.

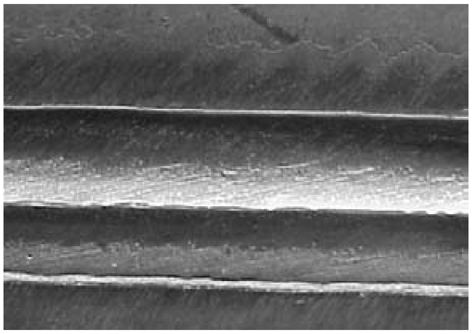

Figure 4. This multiple pass Tandem GMAW weld has a finished appearance that resembles a Submerged Arc Weld.

Opportunities

Lincoln Electric Professional Programs

Blodgett's Design of Welded Structures

September 24-26, 2002
Blodgett's Design of Welded Structures is an intensive 3-day program which 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 and Duane K. Miller. 2.0 CEUs. Fee: $595.

Blodgett's Design of Weldments

October 29-31, 2002
Blodgett's Design of 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 and Duane K. Miller. 2.0 CEUs. Fee: $595.

Fracture & Fatigue Control in Structures: Applications of Fracture Mechanics

October 15-17, 2002
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, see

http://www.lincolnelectric.com/knowledge/training/seminars/

Or call 216/383-2240, or write to Registrar, Professional Programs, The Lincoln Electric Company, 22801 St. Clair Avenue, Cleveland, OH 44117-1199.

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Lessons Learned in the Field

Contributed by Lon Yost, Group Leader, FCAW & SAW
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Beware the Obvious Conclusion!

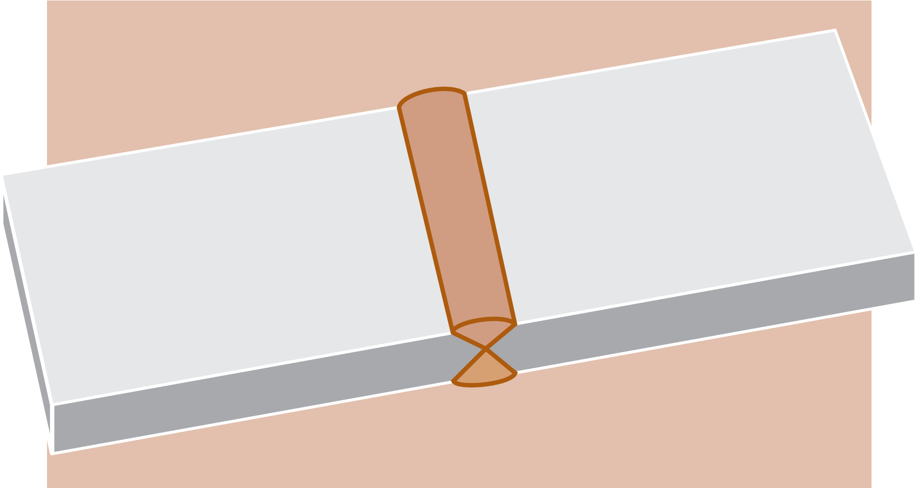

Figure 1. Test plate with flange splice.

The most dramatic example of a lesson I learned in the field occurred about five years ago. At the time, with two decades of welding industry sales and technical support experience under my belt, I thought I had pretty much "seen it all." As it turned out, I was about to get my come-uppance, and learn a lasting lesson in the process.

The Initial Trouble Call

My responsibilities in the Welding Technology Center of The Lincoln Electric Company include direct customer support. One day in the early days of the use of high performance (HP) steel, I received a trouble call from a bridge fabrication shop that was having cracking problems while welding a test girder for the Federal Highway Turner Fairbanks Research Lab. This HP steel had a 70 ksi (485 MPa) minimum yield strength with low sulfur and carbon content, as compared to A852. I asked the usual questions and learned that the weld, specifically, a complete joint penetration groove weld, had passed the fabricator's procedure qualification tests, but for some reason, it was failing on the job. The transverse and longitudinal cracking was delayed, taking three days to show up. The fabricator was using LA -100 electrode and 960 flux, and welding in accordance with the *AWS D1.5 Bridge Welding Code*.

To our consternation, the cracking problem persisted

Together with the customer, I carefully reviewed the possible causes. The CJP groove weld was on a 1-5/16 in. (33 mm) thick plate (Figure 1), so the potential for high residual stresses existed. I also thought we might be picking up some alloy out of the base material. This scenario led me to recommend slowing down the cooling rate through increasing preheat and interpass temperature, trying to minimize the influence of the base metal on the weld deposit.

The Second Failure

The fabricator made another attempt, following all of my recommendations. To our consternation, the cracking problem persisted. At this point, I was having a hard time figuring out what we could have missed. Since the test girder was being welded for the Federal Highway Administration, their personnel became involved. The problem was starting to mushroom. Eventually, there were a lot of people giving a lot of opinions about what was really going on.

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The Third Attempt

For the third attempt, two representatives and one consulting welding engineer from the Federal Highway Administration, a representative from the steel supplier, and yours truly all convened at the fabricator's facility. When we got there, we went to the office to review as much as we could, including drawings and joint designs. Once we were done reviewing the paper side of the job, we went into the shop to investigate details related to the handling of consumables, what they were doing to determine preheat, and so forth.

I was still convinced that the problem was somehow related to the steel. It just seemed to me that if we had the right preheat and interpass temperature, that would solve the problem. A tour of the shop seemed to lend some credence to my theory. I observed:

- Low winter time ambient temperature in the unheated shop
- Flux was being heated in a holding oven (Figure 2), rather than in a true flux drying oven
- The welding set-up would not permit access to the bottom of the plate for heating

We dealt with the lack of access to the bottom of the plate by increasing the preheat substantially beyond levels required by AWS D1.5. We stayed there while the CJP groove weld was again attempted on the bridge girder. In this case, the third time was a charm—the weld did not crack that day, nor in the subsequent days. But the mystery of the first two failures remained.

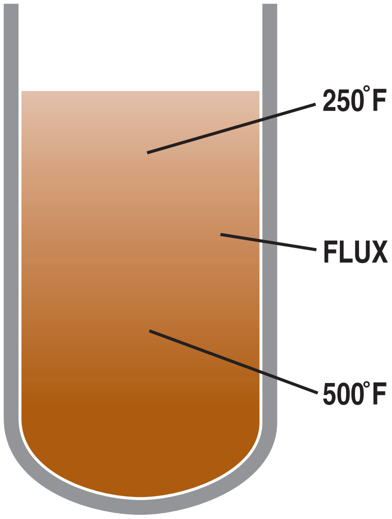

Figure 2. A flux holding oven.

Lab Testing of the Failed Welds

Sections of the failed welds were distributed to the Federal Highway Administration, Lincoln Electric, and the steel supplier for analysis. After returning to our Welding Technology Center, I subjected my sample to a full array of metallographic tests in our lab. Upon analyzing the results, Marie Quintana, Lincoln's Manager of New Products, Consumables, felt that we were dealing with a case of hydrogen assisted cracking in the LA100 filler metal (Figure 3). This was something I hadn't considered. My twenty years of experience had included many examples of steels experiencing hydrogen assisted cracking, but never had weld metal been more sensitive to this type of cracking than the base metal. New developments in base metals, such as this HP steel, resulted in a new possibility. I had assumed that when you're having a cracking problem, the steel is to blame. But this time, my assumptions had misled me. The problem was actually due to the susceptible chemistry of the weld.

My assumptions had misled me

It turned out that on the third attempt at the weld, our team effort to supply more than sufficient preheat, to maintain interpass temperature and to

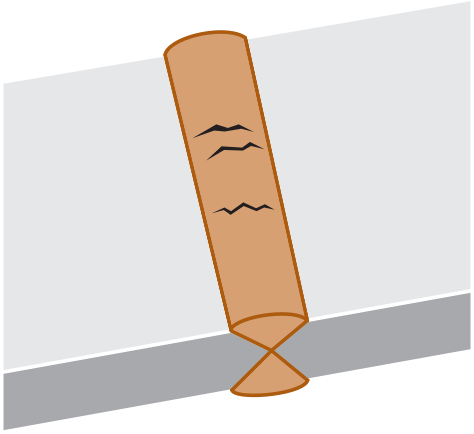

Figure 3. Weld sample with hydrogen assisted crack.

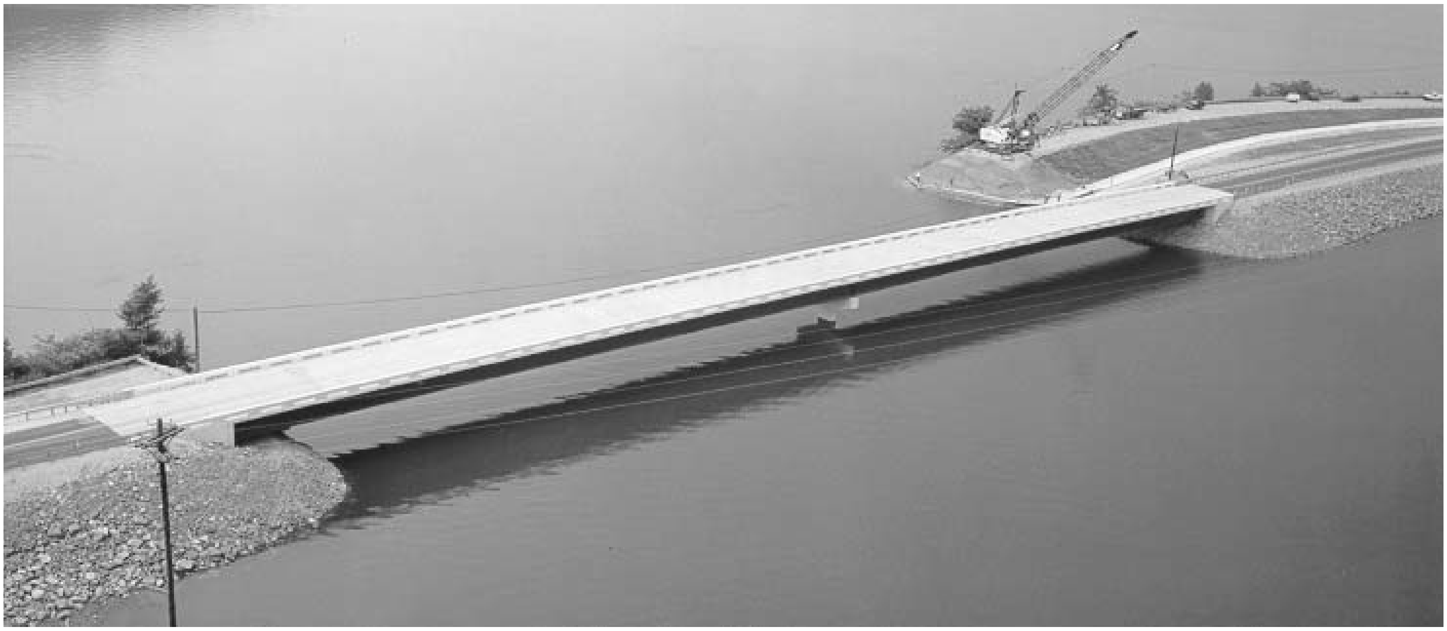

Figure 4. Girders for highway bridges such as this one require multi-pass CJP groove welds.

meticulously condition the flux had actually overcome this tendency to hydrogen assisted cracking. Even after several days, no cracks appeared. At that point, the customer and the Federal Highway Administration were satisfied.

What Took Me So Long?

I was just mystified at how I could have spent two decades in this industry, and never before run into a diffusible hydrogen cracking problem attributable to Lincoln's LA100 electrode. So I tried to remember all the times in the past when I had recommended the use of LA100. It became apparent to me that most of the applications for which I had suggested LA100 had been on projects which entailed small, single pass welds—situations that were very different from this multi-pass CJP weld on a relatively thick bridge girder such as the one shown in Figure 4.

It was a humbling experience to admit to my professional associates on this job that the actual problem was not in the HP steel, but actually in my weld metal. And it certainly taught me to look beyond the obvious when attempting to diagnose and solve a weld cracking problem.

The Consequences

As an outgrowth of this cracking problem and some other similar cases, the use of controlled hydrogen fluxes has broadened. Controlled hydrogen submerged arc fluxes have been specifically designed to resist moisture pickup and aid in the diffusion of hydrogen out of the weld deposit as the weld is being made. Different welding consumables have been tested to determine the best consumables for welding HP steel. Information about the recommended consumables is available from the American Association of State Highway and Transportation Officials (AASHTO) in the *Guide Specifications for Highway Bridge Fabrication with HPS70W Steel*, which can be accessed online at *www.aashto.org*.

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"A Critical Exchange"

Welding in the Sculpture Studio

By Carla Rautenberg
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"It's magic," declares Amie Laird McNeel when she is asked to talk about welding and its application in the sculpture studio. McNeel, an accomplished sculptor and Chair of the Sculpture Department at the Cleveland Institute of Art, is dedicated to sharing that magic with her students. She came to the profession in a roundabout way, starting as a marine biologist documenting the migration patterns of humpback whales. But it seemed to her that marine biologists spent a great deal of time communicating their findings to other marine biologists, and she now says, "I didn't think I could make a difference in that field." Instead, she turned her skills of observation and thoughtful analysis to the creation of art, and she fell in love with the medium of steel.

Seeing space as a physical material

It is clear from a single conversation with McNeel that she is equally passionate about creating art and teaching it. "Teaching, for me," she says, "is a way of not only sharing what I have learned over the years, but of exploring new ideas and possibilities every day." She regards making sculpture as "a way of maintaining a critical exchange between hands, materials and tools."

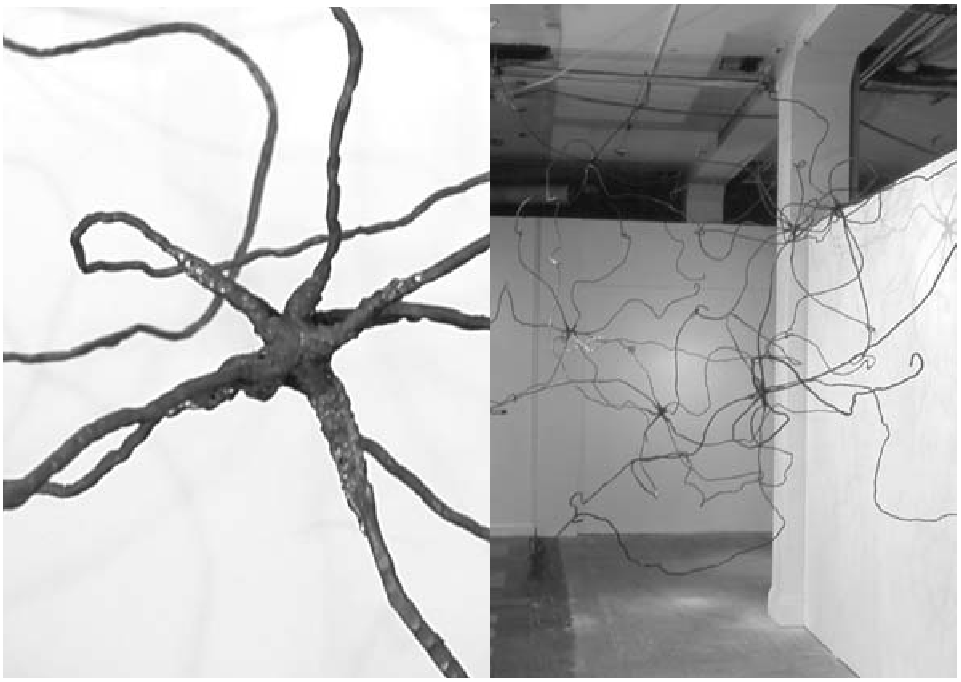

Figure 1. The close-up on the left shows one of the welded connections Jeff Guhde used to create his sculpture "Stretch and Reach," shown on the right.

Two Student Sculptors

McNeel referred *Welding Innovation* to two of her sculpture students whose work is represented here. Jeff Guhde, class of 2004, describes MIG welding as being "just like hot glue." To create the six segments that compose his "Stretch and Reach" (Figure 1), he explains, "I forged these centers out of what started as a cube, and then all of the linear extensions were rods that I forged just a little bit to get a hammered texture, and then they were welded on to each of the centers. So welding is not a predominant design element, but it was used just as a means of connecting the pieces." Guhde was drawn to working in metal initially because of the structural quality of steel, and what he refers to as the "immediacy" of welding. On a more philosophical level, he wants to explore the way that sculptural forms organize the interior space in which they are installed. He says, "It's something that my teacher, Amie, got me started on—seeing space as a physical material."

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Figure 2. Recent CIA graduate Trevor Korns created "Winged Lion" using scrap steel and MIG welding.

Having grown up on a farm, McNeel learned early to work with her hands, and welding came fairly naturally to her. She had this in common with another of her students, Trevor Korns, who received his Bachelor of Fine Arts from the Institute this year. He credits his fascination with creating mythical creatures to having grown up around animals on his parents' farm. His sculptures are made from scrap steel and occasionally cut-up pieces of old machinery, and fabricated using a MIG welder. Korns describes his "Winged Lion" (Figures 2 and 3) as follows: "The self-destructive nature of humanity is represented by the death of the winged lion. I used the winged lion to represent humanity because of the predatory status of the lion and because it has the ability to fly."

"Thoughts Existing in Space"

Amie McNeel refers to her sculptural work as "thoughts existing in space." Some of her pieces, for example, "Fins I" (Figure 4) and "Fins III" (back cover), seem to evoke the machinery of the farm and a lost agricultural Eden. "Fins II" (Figure 5) projects more of an industrial aspect. However, McNeel insists that "It is not nostalgia that motivates this work, but a need to reevaluate such ideas as obsolescence, necessity, progress, ingenuity, and physical labor." The 10 ft. (3m) diameter work entitled "Gaze" (Figure 6) is a visual exploration of movement without any actual moving parts. Figure 7 depicts McNeel installing "Gaze" for an exhibition.

Teaching the Welding Part

McNeel describes her teaching process with great animation. Asked how she begins, she replies, "I learned from one of my instructors that you let people experience the material first, and try to do it on their own, as long as it's safe. Teach them safety. And teach them how to use the tool. I break down the functions of the tool…so they can problem-solve if there's a variable that keeps them from achieving a good weld."

Since steel is expensive and requires practice to manipulate, McNeel has her students do their initial design work using materials such as paper and cardboard. As she puts it, "They design out of a material that has the same geometric qualities but less demands. And then they move to steel."

The beginning students learn three methods of joining: oxy-acetylene welding, oxy-acetylene brazing, and gas metal arc welding. "They feel less intimidated by the wire feed welder, so I teach them harder ones first," says McNeel.

In the second semester, students learn to cast bronze and aluminum and, in due course, are introduced to gas tungsten arc welding of aluminum, and in some cases, steel.

McNeel laughs as she explains, "When the students have to buy their first plate of steel, they're shocked. It's 80 bucks for a sheet of 1/4 in. (6 mm) steel. Then, they start looking at all the scraps in a very different way. So it becomes precious once they put a monetary value on it. With aluminum and brass and different alloys of steels, then they start to really appreciate their designs. They become much more focused on practicing because they don't want to screw it up. We balance mechanical joinery, drilling, bending, designs of connections, we practice mechanical joinery, stitching, sewing, pinning, using steel dowels. They practice design along with just welding. They learn how to choose what's appropriate design—when to weld, when to pin and bolt, when to adjust."

They realize how giving and flexible steel is

A Commitment

She goes on, "Then, we start getting philosophical about welding. Because it's magic. Then they realize how giving and flexible and malleable steel is. But it takes a few years before their designs and their ability and practice all combine to the point where they can say, isn't this magic? Where you can take a metal and you can establish a molten pool of it, and only in that molten pool, when you have that arc right, and that gas shield right, will it accept this material, and it'll agree to become molten, and it'll agree to merge with this base material, and you've made a permanent understanding, you've established a weld. That piece is now one piece. Now what kind of a commitment is that? You've decided this form is worthy of being a permanent thing. You kind of push them to realize that their decisions are not casual."

McNeel sums up her experience as teacher and artist with a wry grin, saying, "Students are kind of dumbfounded with the patience you have to have with yourself and with the process in order to learn it when you deal directly with materials…it takes practice. People don't like to practice. Just the act of doing it sometimes is the most important thing."

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Figure 3. A close-up of the Trevor Korns' mythical "Winged Lion."

Figure 4. "Fins I" (steel, wood, rubber, cables, 10 ft. [3m] long, 4 ft. [1.2 m] in diameter) by Amie Laird McNeel.

Figure 5. "Fins II" (steel, wood, plastic, cables, 9 ft. [2.7 m] long, 5 ft. [1.5 m] in diameter) by Amie Laird McNeel.

Figure 6. "Gaze" (steel, cables, 10 ft. [3 m] in diameter) by Amie Laird McNeel.

Photograph by MJ Toles

Figure 7. Amie L. McNeel, Chair of the Sculpture Dept. at the Cleveland Institute of Art, installing her steel welded sculpture, "Gaze."

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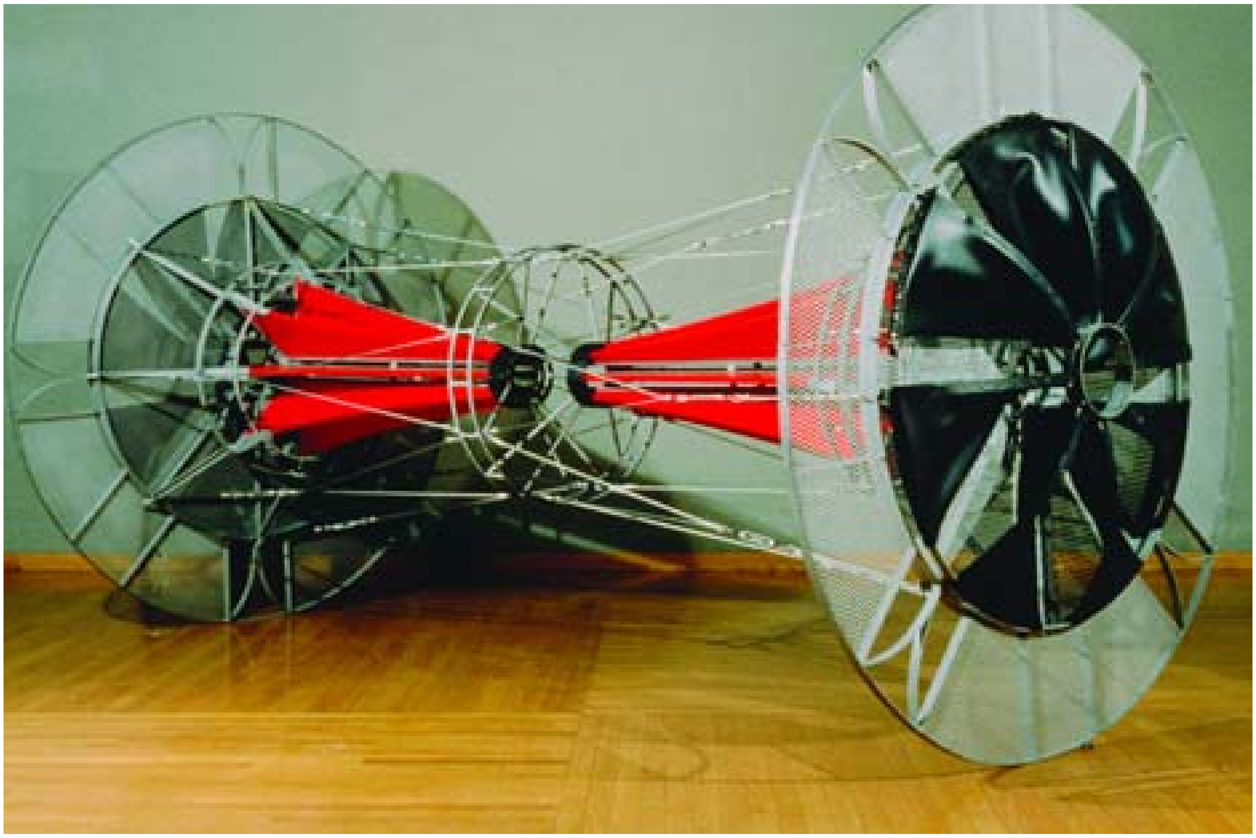

"Fins III" (steel, wood, rubber, cables, 14 ft. [4.3] long, 6 ft. [1.8 m] in diameter) is just one example of Amie Laird McNeel's welded sculpture. See story on page 19.

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