Welding Process Comparison Study

May 8, 2003

EXECUTIVE SUMMARY

A theoretical welding process comparison was completed for longitudinal welding ½" thick A 36 flat rolled carbon steel product in 5" wide and 18-24" diameter rings. It was found that from the six different joining options that appeared the most feasible for the application, double-sided GMAW/SAW combination would be the most likely to succeed. At the same time, Electric Resistance Flash Butt Welding remains a strong contestant for the best joining process, depending on the production volume and possible arrangements with equipment manufacturers.

BACKGROUND

The customer intends to make 18-24" diameter rings by rolling ½" thick x 5" wide carbon steel A 36 bar stock and welding a longitudinal seam along the 5" length. The intent is to machine off excessive reinforcement, as well as the beginning and end of the weld, then expand the welded rings until they yield plastically and become perfectly circular. Reportedly, the final product will be coated with a polymer and inserted on the ID of welded and coated linepipe.

The production volume is unknown at this point, however, a 200 welds/8 hour shift were assumed for this feasibility study. To increase productivity, several rings were to be welded with one setup and full penetration, single-pass welds are desired. Weld automation is imperative, while weld quality has to be consistent.

OBJECTIVES

The purpose of this study was to examine the most economical welding processes available for this application and recommend one optimal solution from a joint preparation, capital investment, weld quality and consistency standpoints.

METHODOLOGY

Several assumptions were made for the sake of the process comparison. The cross section to be joined was ½" thick and 5" long, carbon steel with a minimum 30 ksi yield strength. The joint efficiency was to be 100%, free of internal flaws such as lack of fusion/penetration, porosity and cracks.

It was assumed a volume of 100-300 welds/shift could be made depending on the welding process chosen.

While the initial assumption was that single-pass one-side full penetration Submerged Arc Welding (SAW) is to be used, other processes were to be considered, based on the technical literature that places the number of total welding/joining processes to 250 (Ref. 4). A theoretical optimization study had to include the following considerations and associated capital and labor costs:

-Joint preparation: consistency of alignment, quality of saw cut edges, gap size
-Fixtures: need for clamp-down, backing bars, run-on, run-off tabs
-Process efficiency: single- vs. double-pass arc welding, weld quality, automation
-Post weld processing; removal of excess weld, yielding during expansion of ring

A total cost vs. production volume plot was to be produced for each welding process alternative to include the approximate amortization cost for the capital investment.

RESULTS AND DISCUSSION

Several welding/joining processes were considered for this application.

1. SAW single-sided, full-penetration one pass weld (customer's preference)
2. SAW two-sided, partial-penetration, two-pass weld (no back gouging)
3. GMAW, two-sided, two-pass welding
4. GMAW/SAW two-sided, two pass welding
5. Flash Butt Welding, direct Electric Resistance
6. Laser/GMAW hybrid single-sided, full penetration

One major criterion to be addressed will be joint fitup and accurate alignment in preparation for welding. The other criteria for comparison have already been mentioned in the previous section.

1. SAW single-sided full-penetration one pass weld, Square-butt Joint

Several assumptions have to be made for this option, including:

-A clamp-down fixture is built (bought) to keep mismatch under 0.040"
-Use run-on and run-off tabs 3/4" long between welds
-Consistent gap size of 3/16" with +/- 0.020 tolerance
-Backup support (gas-assisted copper bar, ceramic or flux bed)
-Acceptable edge cleanliness – free of saw cutting oil or other contaminants
-Automatic travel (side-beam or carriage) for the SAW welding head

Under these conditions, the following parameters are recommended using an EM12K wire such as ESAB SA 81 and an active flux such as ESAB 350.

wire size	Current	Voltage	Travel	Electric stick out
3/16"	~ 1100 amps DC	~ 34 - 36	16 - 18	1 ¼" to 1 1/2"

ADVANTAGES include:

- Use of a welding process familiar to the fabricator
- Relatively inexpensive welding power supply

- System remains multifunctional for future seam welding operations

DISADVANTAGES include:

- Poor reproducibility – risk of variation from lack of penetration to complete burnthrough in the same weld – difficulties in maintaining good fitup
- Medium productivity, long set-up times (assuming 5 rings/setup, estimate setup 3 + welding 2 minutes, separate 5 minutes=10 minutes, i.e. 2 minutes/ring or 30 rings/hour, or 240 rings/shift).
- Need for extensive machining on the root and edges ($$$?)
- Operator-dependence, in spite of automation…
- Need for building side-beam and fixturing ($$$)

2. SAW two-sided two pass weld, no backgouging, Square-butt Joint

This version of SAW would be less sensitive to fitup problems, but would also be less productive. In essence, the same setup would be needed as in case # 1, but welding parameters could be more usual. Current of 500-500A, arc voltage of 30-32 V and travel speed up to 20 IPM could be easily used to weld more than half of the thickness. Flipping over the assembly and welding from the ID side without backgouging should finish the weld.

One more difference would be the geometry of the SAW welding head that should be able to reach in 36" inside the five welded ring subassembly. This is not a problem, but one more complication.

ADVANTAGES include (relative to the single-pass full penetration SAW):

- Less susceptibility to fitup, use of welding parameters more suitable for (typical to) SAW
- No need to buy new SAW power supply
- Better chances for reproducible good weld quality
- Relatively quick parameter development time

DISADVANTAGES include:

- Lower productivity; less than 120 rings/shift
- Weld reinforcement variations – to be removed by excessive machining
- Still needs fixture and sidebeam for automation – dependent on operator skill

3. GMAW welding, Two-sided, no backgouging

Another traditional arc welding process that could be used for this application is Gas Metal Arc (GMAW) welding. While the typical penetration capabilities of typical 300 A power sources for GMAW do not reach ½" in steels, modern Pulsed Spray systems, with use of tubular (metal- or flux-core) wire electrodes could easily reproduce the two-sided, no backgouging SAW option mentioned before.

ADVANTAGES include:

- High welding speeds
- Better chances for reproducible good weld quality (no chance of slag entrapment between passes)
- Proven technology, potential for several future uses

DISADVANTAGES include:

- Need to purchase additional GMAW power source
- Development time
- Need to build/buy carriage and side-beam

4. GMAW/SAW WELDING COMBINATION, TWO-SIDED, NO BACKGOUGING

This approach would necessitate two welding stations, one for the OD (GMAW) and one for the ID (SAW).

ADVANTAGES include:

- High welding speeds
- Better chances for reproducible good weld quality (no chance of slag entrapment between passes)
- Proven technology, potential for several future uses

DISADVANTAGES include:

- Need to purchase additional GMAW power source
- Development time
- Need to build/buy carriage and side-beam

5. FLASH BUTT WELDING (ELECTRIC RESISTANCE WELDING)

This welding process uses electric current passed between the pieces to be joined, with simultaneous application of forging force. As Figure shows, the thermal energy generated via Joule heating can be expressed as a function of the current squared, resistance and time ($Q=I^2 R\ t$). Expressed differently, the power generated during welding can be expressed by the electrical power in the secondary circuit of any AC transformer:

$$P = \int (I \times V) \cos\theta \, dt$$

where: I – secondary current, A (usually 10-100,000A)
V – secondary voltage, V (usually 20-50 V)

Cos θ- power factor < 1 reflecting on reactance losses

The unit of power is usually given in (kVA), that multiplied by time results in energy. For example, a single-phase resistance spot welder for sheet up to 1/8" thick is typically rated at 50 kVA. In contrast, the power needed for FSW is much larger and can reach 300-750 kVA, depending on the size of the cross section to be joined. Therefore, they can cost anywhere between $300-500K, including fixturing, axial mechanical displacement and timing control units. For the ½" x 5" cross section, the total welding time (including clamping, weld cycle and release) can reach 20-30 seconds.

ADVANTAGES include:

- Excellent reproducibility and very good weld quality (solid state weld)
- Minimal operator skill required – independent of operator abilities, completely automated
- Fitup and alignment problems are eliminated – automatic clamping jaws are part of the system
- The process is practically insensitive to saw cut edge irregularities and possible organic contamination
- Excellent productivity (potentially can produce 60/hour, or 360/shift)

DISADVANTAGES include:

- Complex equipment, high capital- and operating (power) costs – see a typical and smaller 100 kVA unit in Figure 1

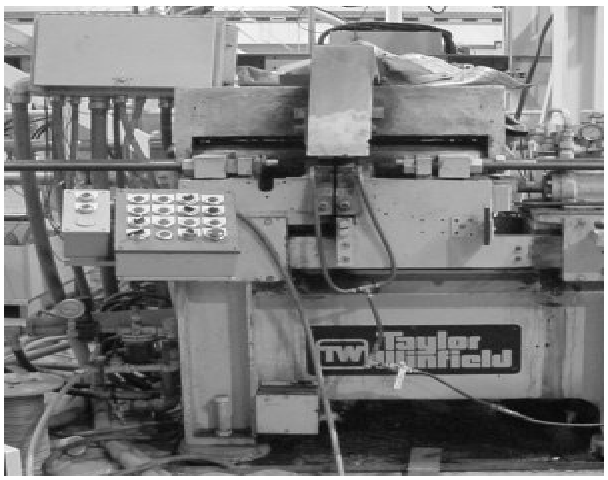


Figure 1. Typical refurbished 100 kVA FBW from Taylor-Winfield website

- "Dedicated", specialized system- lack of flexibility to adopt machine for other future joining operations
- ID and OD "flash" have to be removed by machining after welding
- Circumferential "allowance" has to be included in the strip length to compensate for the upset (could lose up to 1" of steel on each ring)

6. SINGLE-PASS, ONE-SIDED FULL-PENETRATION HYBRIG LASER/GMAW WELDING

A relatively new but established process (Ref. 1-3), a combination of deep penetration LBW and good deposition rates of GMAW has become more attractive.
As the following schematics show, this "hybrid" welding process uses a 1-2 kW power Nd-YAG laser in conjunction with a 300 A GMAW torch mounted on the same welding head.

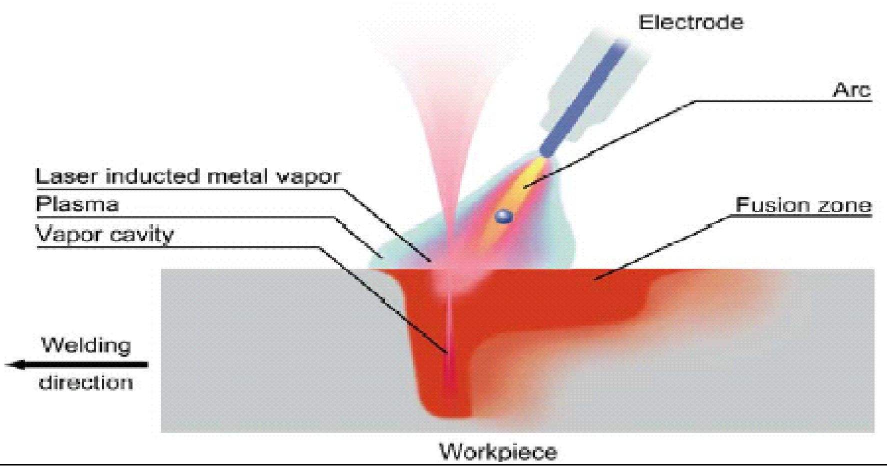


Figure 2. Schematic representation of the Laser/GMAW hybrid welding process

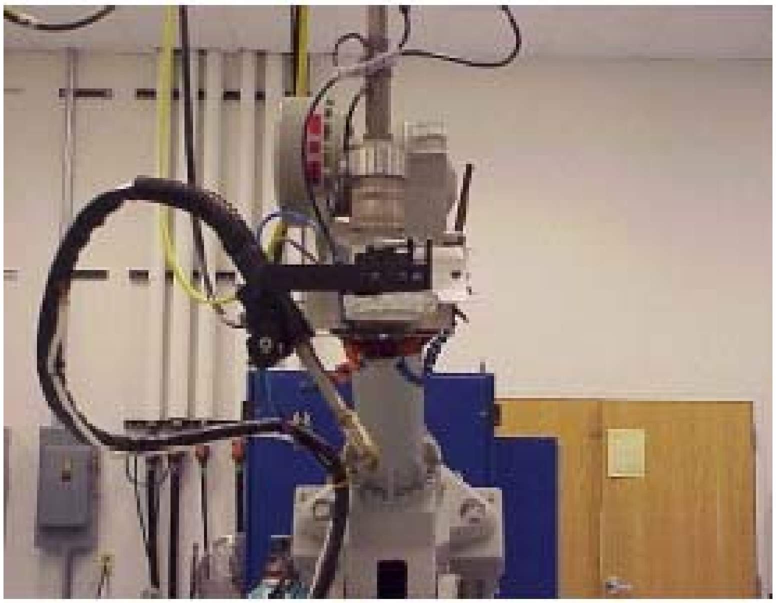
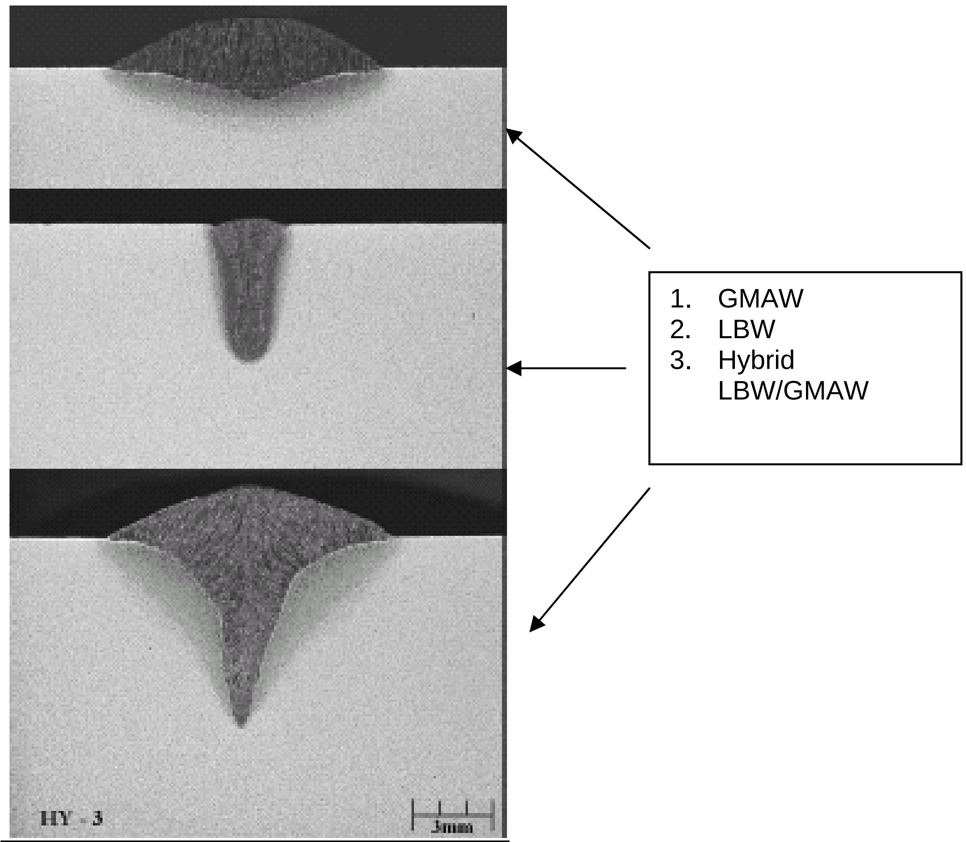


Figure 3. View of the motion system (attached to a welding robot) – can be mounted on a simple side-beam carriage as well



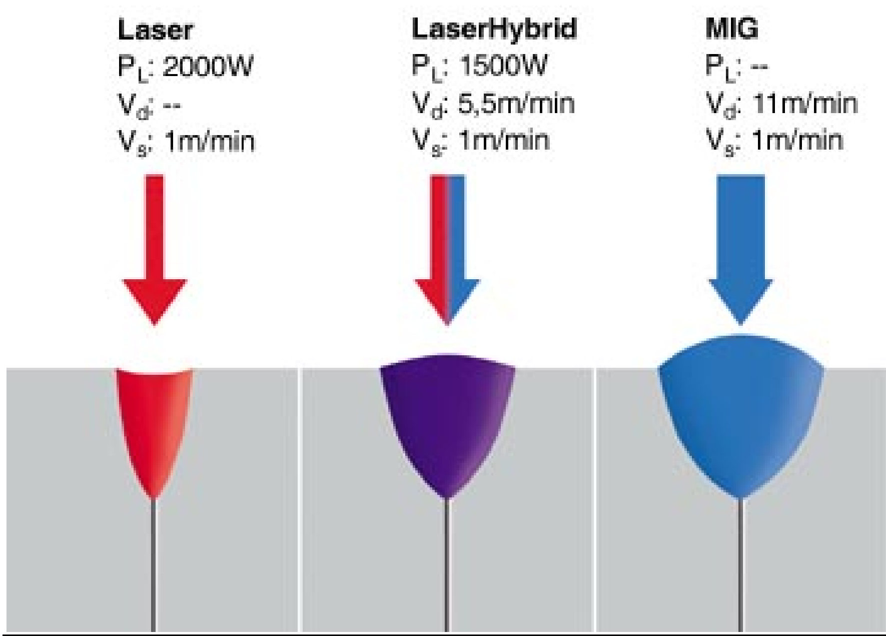


Figure 4. Schematic representation of the combined advantages of each individual welding process

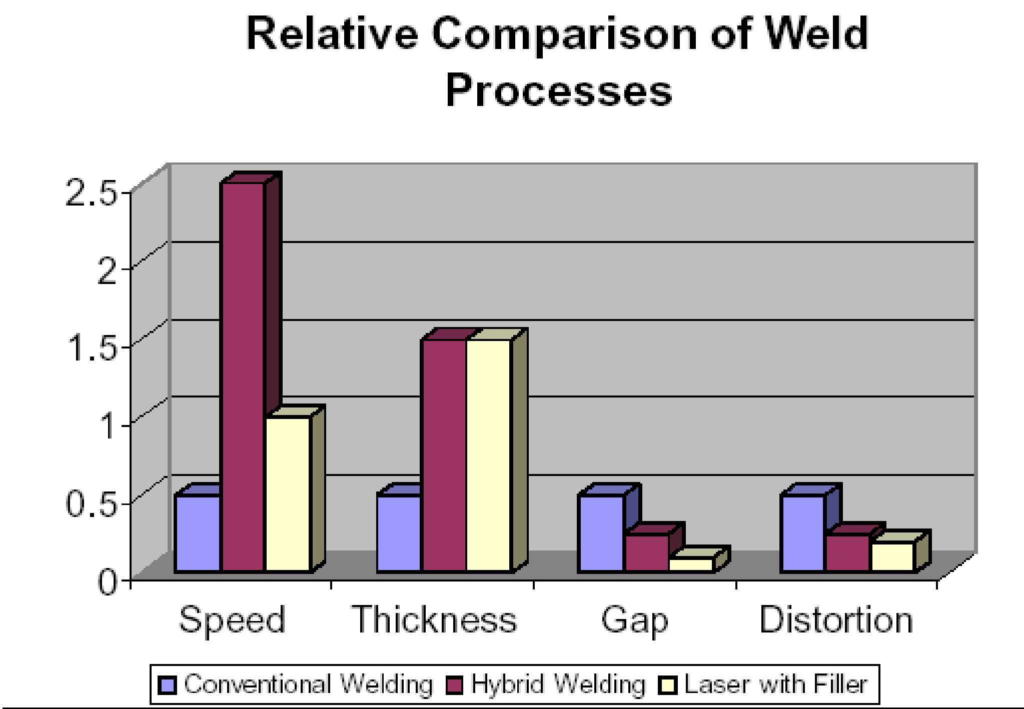


Figure 5. Qualitative comparison between the two individual welding processes and the resultant hybrid. Note the much higher productivity, penetration capability of the hybrid, as well as the lower susceptibility to gap variations and less distortions.

ADVANTAGES include:

- Less susceptibility to fitup and gap variations
- High Productivity (up to 5 times traditional arc welding speeds)
- Good reproducibility, single-sided access
- Good customer image - technological innovation
- Could be used for other future applications (separately or together) – gain three new welding processes

DISADVANTAGES include:

- Relatively high equipment costs
- Susceptibility to edge cleanliness variations
- Longer development time (new process), less available systems and experts

COMPARISON BETWEEN SUGGESTED PROCESSES

The following brief "Value Engineering" approach to process comparison is based on a 1 (poor) to 5 (excellent) rating of each factor. Final ranking is based on the highest total assigned to each welding process.

Several assumptions have to be made for this comparison, such as:

- Brand new welding equipment and fixturing is needed
- Perception by customer is equally positive
- An average volume of 100-300 parts/8 hour shift are produced

Note that the factors were not weighed in terms of relative importance!

FACTOR	1. Single pass SAW	2. Two Pass SAW	3. Two pass GMAW	4. Flash Butt	5. Hybrid LBW/ GMAW
Capital costs	3	3	3	1	2
Operating costs	4	4	4	2	3
Flexibility of capital for future use	4	4	5	1	3
Reliability of operation	2	4	4	5	3
Development time and costs	2	5	5	3	4
Productivity	3	2	2	5	4
Weld quality	3	3	3	5	4
Operator skill level required	3	3	3	5	2
Post weld processing costs	3	4	4	3	4
TOTAL	**27**	**32**	**33**	**29**	**29**
RANK	**IV**	**II**	**I**	**III**	**III**

Note: Buying used equipment or subcontracting work at job-shop would probably upset the above ranking toward FBW and Laser/GMAW Hybrid welding. At the same time, a total volume exceeding 50,000 will also heavily favor FBW. Additional weighing of each factor depending on the customer's perspective will be needed.

Initial private conversations with manufacturers and job shops representatives also give hope for more "creative" solutions to start the project with subcontracting first few hundred preformed production rings.

CONCLUSIONS

Based on this theoretical evaluation and information available at this point, the following welding processes are recommended, in a decreasing order of applicability for the present job:

1. GMAW two-sided
2. SAW two-sided
   (Hybrid GMAW on OD followed by SAW on the ID – not included)
3. Laser/GMAW hybrid – single-sided full penetration
4. Flash Butt Welding – one step, full penetration
5. SAW single-sided full penetration

The overriding factor in this analysis was the cost of joint preparation and fitup for obtaining a consistent weld at medium-to-high production volume.

RECOMMENDATIONS

1. Single-sided SAW full penetration weld option is not recommended because of anticipated weld penetration problems due to poor fitup and borderlinish SAW process capabilities
2. Validation experiments are recommended for 1) double-sided SAW and 2) double-sided GMAW as well as 3) hybrid GMAW/SAW options using solid and tubular wires – can be performed by the author:

   The edge preparation costs, welding times and quality should be verified by examining welded samples. For each welding process, ten pairs of 10" long, 6" wide specimens would be required. Nondestructive evaluation (Visual, LP and MP) of each weld will be followed by destructive testing including transverse tensile- and bend tests, metallurgical macro examination and hardness testing.

   The cost of this validation experimental work on three options is estimated to **$3,750.00** and will take 3 months to complete from the time specimens are received.

3. For a complete comparison, further validation experiments are recommended for Flash Butt Welding at Taylor-Winfield Company or Automation International (**$3,000.00**) and Hybrid Laser/GMAW at EWI? (**extra $3,000?**)

REFERENCES

1. Graf, T. 2003. Laser-Hybrid Welding Drives VW Improvements. *Welding Journal* 82(1): 43-s to 48-s.
2. Denney, P. 2002. 'Hybrid Laser Welding' for Fabrication of Ship Structural Components. *Welding Journal* 81(9): 58-s.
3. Dayal, A. 2002. Latest Advances in Hybrid Laser Welding. *Innovation* 28(12).

4. American Welding Society, Welding Handbook, Volume 2, Ninth Edition
5. Private communications - Dr. Ernest Jan, ESAB Co., Dr. Jerry Gould, EWI,