Evaluation of Metal Core Arc Welding for Bridge Fabrication

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Alberta Transportation and Infrastructure

and

Centre for Transportation and Planning

By

Ludwig Kusiak. P.Eng

Ferrous Fabricators

And

Dr. J.B. (Barry) Wiskel, P.Eng

Chemical and Materials Engineering

University of Alberta

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EXECUTIVE SUMMARY

An evaluation of the MCAW (Metal Core Arc Welding) process for use in welding bridge components – such as guard rails, pedestrian rails and miscellaneous items - was undertaken in conjunction with AIT (Alberta Infrastructure and Transportation) and C-TEP (Centre for Transportation and Planning). Three independent fabricators (using C.W.B. reviewed welding procedure) MCAW welded test samples of 3/8” thick 44W steel in 3 joint configurations: fillet, butt and lap. Each MCAW weld sample was tested for quality/acceptability according to CSA Welding Specifications using 4 quality test procedures: visual, magnetic particle, ultrasonic and bend testing. For comparative purpose identical weld samples were produced using a SMAW (shielded metal arc welding) process. The MCAW welds were found to equal or exceed the quality of the SMAW process for all joint configurations. This study concludes that MCAW is a suitable welding process for bridge components using C.W.B welding procedures.

INTRODUCTION

At the present time Alberta Infrastructure and Transportation (A.I.T.) allows only two welding processes (SMAW and SAW) for the fabrication of girders, guard rail, pedestrian rails, and miscellaneous items used in bridge construction. Though both the SMAW and SAW processes have some advantageous features, the MCAW (Metal Core arc welding) process offers fabricators a more economical means to fabricate these bridge components. Therefore the focus of the work presented in this report will be to determine if quality welds can be consistently produced using the MCAW process for certain bridge components and whether this welding process merits acceptance into A.I.T. specifications and standards. Because of its proven track record, the SMAW process will be used as the reference and basis of comparison for all test welds produced by the MCAW process.

BACKGROUND

FCAW welding was used in the late sixties and early seventies by industry but was not adopted by A.I.T. (Alberta Infrastructure and Transportation) for bridge components fabrication. Though the process proved more economical than SMAW, the weld metal quality was inconsistent. Faults in the manufacturing of the tubular wire used frequently resulted in unacceptable levels of porosity. However new advances in tubular wire manufacturing (i.e. wire annealing) and their incorporation into semi and automatic welding has eliminated the porosity problem. Since metal-cored processes (MCAW) are more economical than SMAW, fabricators have requested that these be included into A.I.T.'s specification and standards. Hence, A.I.T. has considered reviewing the Metal Core Arc Welding process for certain bridge components and thus provides the impetus for the work presented here.

WELD PROCEDURE AND POST WELDING EVALUATION

In consultation with A.I.T. personnel, the evaluation of MCAW welding for bridge components consisted of 2 parts: 1] welding of replica test samples using both MCAW and SMAW process and 2] certification of the weld quality under the requirements of CSA Standard W47.1 and W59.03.

Weld Procedure

For welding of both MCAW and SMAW tests samples, three (3) independent metal fabricators were part of this study. Each fabricator was required to follow C.W.B. reviewed welding procedures with valid C.W.B approved welding tickets for the personnel. In total 8 different welders were used in welding the test samples made from G40.21-Grade 44W steel. The SMAW welds were made with E7018 electrodes. The MCAW welds were made with metal-cored wire electrode with an allowable diffusible hydrogen content of 4ml/100g of weld metal. Each fabricator (where possible) had three different welders producing three samples for all weld configuration using both SMAW and MCAW. The specimens followed the C.W.B. format as described in W47.1.

The weld configurations tested in this study include:

A) butt welds (without backing)

B) butt welds with backup plate

C) 6mm fillet welds on both sides of the T-joint

D) one sided lap welds

In total 123 welds were made. The total of each weld joint configuration and weld process is shown in Table I.

Table I – Number of welds for each Joint configuration and Process

Joint Configuration	MCAW	SMAW
Butt Welds (36 total)	18	18
Butt Welds with Backing Plate (18 total)	9	9
Fillet Welds (42 total)	21	21
Lap Welds (27 total)	15	12

Weld Quality Evaluation

Quality assessment of all welds was conducted by AITEC (Western) Inc. using the following forms of inspection: visual, magnetic particle, ultrasonic and mechanical bend test (side, root and face) and certified under the requirements of CSA Standard W47.1. Table II below summarizes the potential flaw type detected by each inspection technique.

Table II – Weld Quality Inspection Techniques

Technique	Type of Flaw(s) Detected
Visual	• surface cracks, porosity, unfilled craters, and some slag inclusions. • over welding, under welding, and poorly formed beads • excessive warpage, misalignments and improper fitups
Magnetic Particle (for fillet welds)	• surface cracks or subsurface ones that are very close to the surface
Ultrasonic	• surface and interior discontinuities and inclusions
Mechanical Bend	• relative strength of the welded specimen • failed samples visually examined for discontinuities

Visual Inspection

The visual inspection results for each weld configuration and process are summarized in Table III. Nine (9) SMAW butt welds (with and without backing) failed due poor weld profile. One (1) MCAW butt weld without backing and three (3) MCAW butt welds (with backing) also failed visual inspection due to an excessive height of weld profile (see Figure 1 below). All the fillet and lap welds using the MCAW processes passed visual inspection. Four (4) SMAW lap welds failed visual inspection.

Table III – Summation of Visual Inspection Results

Joint Configuration	MCAW		SMAW	
	Pass	Fail	Pass	Fail
Butt Welds without backing plate	17	1	12	6
Butt Welds with backing plate	6	3	6	3
Fillet Welds	21	0	21	0
Lap Welds	15	0	8	4

Figure 1 – MCAW butt weld (with backing) with excessive weld height

The visual failures associated with each process and weld configuration and the individual fabrication shops are shown in Table IV. Shop #3 was found to have the most weld failures.

Table IV –Visual Inspection Failures for each Fabricator

Fabricator	Butt Weld		Fillet		Lap	
	MCAW	SMAW	MCAW	SMAW	MCAW	SMAW
Shop #1	1	1	0	0	0	0
Shop #2	0	2	0	0	0	1
Shop #3	3	6	0	0	0	3

Magnetic Particle Testing

The results for black on white magnetic particle inspection are summarized in Table V. No weld sample was rejected for either process.

Table V – Summation of Magnetic Particle Inspection Results

Joint Configuration	MCAW		SMAW	
	Pass	Fail	Pass	Fail
Fillet Welds	21	0	21	0

Ultrasonic Testing

The results for the ultrasonic inspections are summarized in Table VI. Both shear and longitudinal wave ultrasonic examination were performed. One butt weld (SMAW) was observed to have 90 mm length of non-fusion and was not acceptable while the remaining joint configurations for both processes were all found acceptable. The three (3) MCAW butt welds (with backing) that were rejected on visual inspection were included in the ultrasonic and all passed ultrasonic inspection.

Table VI – Summation of Ultrasonic Inspection Results

Joint Configuration	MCAW		SMAW	
	Pass	Fail	Pass	Fail
Butt Welds without backing plate	17	0	12	0
Butt Welds with backing plate	9	0	5	1
Lap Welds	15	0	8	0

Mechanical Bend Testing

The results for the mechanical bend tests are summarized in Table VII. Two bend failures were observed with the SMAW butt welds. The MCAW welded butt welds (no backing) passed the mechanical bend. The MCAW butt welds made with backing (including 3 that failed visual examination) all passed the bend test.

Table VII – Summation of Mechanical Bend Test Inspection Results

Joint Configuration	MCAW		SMAW	
	Pass	Fail	Pass	Fail
Butt Welds	17	0	12	2
Butt Welds with Backing Plate	9	0	5	0

Macro-etching

Acid etching was conducted on 36 MCAW welds (21 Fillet and 15 Lap) and on 33 SMAW welds (21 Fillet and 12 Lap). Figures 2 and 3 show the typical penetration profiles for the MCAW and SMAW processes respectively. In general, the MCAW process resulted in greater penetrating weld profiles than SMAW.

Figure 2 – Photo of macro etch for MCAW weld.

Figure 3 – Photo of macro etch for SMAW weld.

DISCUSSION

Visual Inspection Failures

The MCAW welds that did not pass visual inspection were made on butt configurations with and without a backing plate (4 failures). This same trend was observed for SMAW welds but with a greater # of failures (9). This would indicate that butt welding 3/8" plate (particularly with backing), was the most difficult weld configuration tested. For all other weld configurations the MCAW welds exhibited fewer visual inspection failures (1) than the SMAW welds (4).

In addition, it was observed (Table IV) that the majority of visual weld failures (12 out a total of 17) could be attributed to Fabrication Shop #3. Post welding discussion with Shop #3 indicated that the junior welders were used to make the test welds. In addition, the majority of welding undertaken in all the fabrication shops is either with MCAW, FCAW or SAW with SMAW primarily used for tacking. This less frequent use of SMAW may account for the greater number of weld failures observed with this technique

Other Inspection Techniques

All MCAW welds that passed visual inspection also passed subsequent magnetic, ultrasonic and mechanical tests. The butt welds that failed visual inspection with MCAW were tested and found to pass ultrasonic tests. For the SMAW welds that passed visual inspection, two (2) samples failed the mechanical test and one (1) sample failed the ultrasonic. Visual examination of the failed bend samples showed the presence of porosity and a brittle fracture surface – whether the porosity is the cause of the failure is not known.

Penetration Depth

Qualitatively, the MCAW welds (for both fillet and lap configurations) were observed to exhibit greater weld penetration depth. This is attributed to the higher current densities that can be applied with a metal core process. Equivalent current densities with SMAW may result in break down of the flux covering and subsequent defects in the weld. The greater weld penetration associated with MCAW can translated into higher quality welds.

CONCLUSIONS

1] MCAW welding of 3/8" plate in Fillet and Lap weld configurations were observed to pass all CWB quality assurance tests (visual, magnetic, ultrasonic and bend).

2] The MCAW weld quality met or exceeded the SMAW for all weld configurations.

3] The penetration depth of the MCAW welds was qualitatively observed to be greater than for the SMAW.

4] The MCAW process is deemed suitable for welding miscellaneous bridges components (e.g. railings, deck joints etc.)