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BENCHMARK GAS METAL AND METAL CORED ARC WELDING

C. Nicholson

FLEET TECHNOLOGY LIMITED

DEFENCE RESEARCH ESTABLISHMENT ATLANTIC

Contractor Report
DREA CR 1999-166
October 1999

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et développement

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BENCHMARK GAS METAL AND METAL CORED ARC WELDING

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ABSTRACT

Previous investigations carried out at DREA and on its behalf have demonstrated that the gas metal arc welding (GMAW) process using selected electrode wires and shielding gases provides superior weld metal toughness in submarine steels than is the case for the shielded metal arc welding process.

More recently, a past project demonstrated that pulsing power source technology had advanced to a state where GMAW welds should be reliably produced at low enough heat inputs to provide good weld metal toughness and avoid the lack of fusion flaws which have been commonly associated with previous attempts.

Two welded panels were produced using different wire/gas combinations; one of which had shown considerable promise in previous DREA investigations (LA 100/TIME) and the other having shown great potential in manufacturer's technical literature (MC-100/M2). Radiography at +/-20° to normal revealed no objectionable discontinuities and no lack of fusion.

RÉSUMÉ

Des recherches antérieures effectuées au CRDA et en son nom ont démontré que le procédé de soudage MIG utilisant des fils-électrodes sélectionnés et des gaz protecteurs présente une ténacité du métal fondu utilisé dans les aciers de sous-marin supérieure à celle du soudage à l'arc avec électrode enrobée.

Plus récemment, un projet démontrait que la technologie de source d'alimentation électrique par impulsions avait progressé à tel point où que les soudures MIG pouvaient être effectuées avec des apports de chaleur assez bas pour fournir une bonne ténacité du métal d'apport tout en évitant les défauts de fusion associés aux tentatives précédentes.

Deux panneaux soudés ont été produits en utilisant différentes combinaisons de fils et de gaz. L'un des panneaux semblait très prometteur lors de recherches antérieures au CRDA (LA 100/TIME) et l'autre avait révélé de grandes possibilités d'après la documentation technique du fabricant (MC- 100/M2). La radiographie à +/-20° par rapport à la température normale ne présentait aucune discontinuité inadmissible ni d'absence de fusion.

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1. INTRODUCTION

Previous investigations carried out at DREA and on its behalf have demonstrated that the gas metal arc welding (GMAW) process using selected electrode wires and shielding gases provides superior weld metal toughness in submarine steels than is the case for the shielded metal arc welding process. Still, a range of toughness values can be obtained with the GMAW process depending on the welding technique employed. For example, for out of position welding in the vertical position, vertical up progression necessitates weaving and low travel speeds that may lead to relatively inferior toughness properties. Conversely, high travel speeds made possible with vertical down progression lead to very high weld metal toughness. Unfortunately, the latter is accompanied by an unfavourable weld bead shape requiring considerable interpass grinding and can still result in lack of fusion type of flaws.

Over the time period of the previous DREA sponsored projects, there have been concurrent development and availability of advanced power sources with digital pulsing technology. With the use of such power sources, gas metal arc welding stability is considerably enhanced and therefore making sound welds in positions other than flat has become much easier.

At the same time, newer electrode wires are being developed which may further enhance the weld zone properties or enable welding productivity to be increased. Use of metal cored wires instead of solid wires in the GMAW process is one promising approach in this context. Certain flux cored arc welding wires may also offer potential advantages of operator appeal and/or productivity. Before evaluating such newer consumables however, a benchmark needs to be established against which comparisons can be made.

Accordingly, this investigation aimed to make two welds using a state of the art digital pulsed welding power source (Lincoln Powerwave) and two electrode wire-shielding gas combinations. One of these was Lincoln LA 100 solid wire with TIME shielding gas, a combination known from previous investigations to provide excellent weld zone toughness. The second combination employed a metal cored wire (Lincoln MC 100) in conjunction with M2 (argon-2% oxygen) shielding gas. This latter consumable combination was selected due to the extensive testing Lincoln Electric Company had already undertaken to successfully qualify the wire to the US Military specification requirements for use in submarine fabrication.

2. APPROACH

As planned at the outset, after procuring the consumables, considerable effort was spent in examining the effect of welding parameters (current/wire feed speed, voltage, travel speed) on weld bead shape and arc stability. All weld beads were deposited in grooves, and most of these had a vertical up progression. Few beads were also deposited with vertical down progression, however, the travel speeds tended to be quite high and were judged to be unsuitable for semi-automatic welding typical for repair situations. Another consideration in finalizing the welding parameters was that the weld bead not be convex or humpy so as to minimize interpass grinding and to reduce the likelihood of incomplete fusion with the side wall or between the passes.

A final consideration was that the heat input be kept as low as possible since this tends to temper the weld metal deposited in the previous passes and thus leads to improved weld metal toughness though, to some extent, this is at the expense of deposition rate and productivity. Similarly, where ever possible, it was intended to have 50% overlap between the adjacent passes so that some tempering of the heat affected zone caused by the previous bead is accomplished.

The finalized welding parameters were then used to make two short welds, one each for the selected wire-gas combination. Three cross-sections and four side bend specimens were prepared from each weld as a quality assurance measure to ensure that the welds were sound. The finalized welding procedures were then used to make the test welds, and after their non-destructive examination, following specimens were extracted from each weld with the objective of assessing weld metal mechanical properties:

(a) Two cross-weld tensile specimens;
(b) One cross-section for macro-examination and hardness testing;
(c) One 150 mm (6") wide, full thickness face bend specimen;
(d) Five dynamic tear specimens notched at weld centerline,
(e) Up to eight CVN specimens notched at the weld centerline, roughly half from half-thickness location and the rest from 1.5 mm sub-surface location.

3. INVESTIGATION AND RESULTS

3.1 Weld Fabrication

Both the welds were made in 25 mm (1") thick HY 80 steel in a semi-automatic mode, however, travel speed and welding parameters were monitored for each weld pass. Double V-groove preparation was selected to permit balanced welding to reduce distortion, and to minimize the weld metal volume. However, the groove angle selected (70°) was larger than normal (60°) in order to improve accessibility and permit better side wall fusion.

Before commencing welding, the groove and adjacent base plate were preheated to a temperature of 90°C as required by the Canadian Navy Submarine fabrication specifications. However, the interpass temperature was maintained at a relatively low value of 120°C in order to prevent potential deleterious effects of higher interpass temperature on weld metal strength and toughness. While no post-heat was applied, the completed weld was immediately covered with blankets as a precautionary move to minimize the risk of hydrogen induced cold cracking in the weld zone.

The detailed welding procedures employed are outlined in Welding Procedure Data Sheets in Appendix A. It should be noted that the weld heat input per pass employed with the metal cored wire is much higher (1.2 to 2.4 kJ/mm, average 1.83 kJ/mm) than that for the solid wire GMAW process (0.64 to 1.0 kJ/mm, average 0.89 kJ/mm). Further, the metal cored arc welding procedure employs one pass per layer. Such a pass sequence was essential and requires greater welder skill since the rather fluid slag and limited wetting of base metal required that a wide weave and slower travel speed be used to support the weld pool. In comparison, the solid wire weld passes could be deposited with minimal weave thus permitting two passes per layer for most of the weld thickness. The solid wire procedure can thus be considered to be more user friendly. As well, the multi-pass per layer approach leads to considerable tempering and local toughness improvement along the weld centerline, the exact location where the notch of the toughness test specimens is placed.

3.2 Non-destructive Examination

The non-destructive examination comprised visual examination followed by radiography. No significant undercut was noticeable and the weld reinforcement was typically on the order of 3 mm (1/8"). For radiography, two shots were taken for each weld, at ±20° to the vertical. Ignoring 25 mm weld length at each end, the 600 mm long welds were found to be virtually free of crack-like flaws such as lack of side wall or interpass fusion, save for one 4mm indication associated with a stop-start location which is likely a result of operator error. Minor, but acceptable, porosity and slag inclusions, as per CSA Standard W59.1 requirements for dynamically loaded structures, were present, however.

3.3 Mechanical Property Test Results

3.3.1 Cross-weld Tensile Tests

Two specimens were machined from each weld as per the dimensions in CSA Standard W47.1 and tested at room temperature. The following results were obtained:

Table 3.1: Cross-Weld Tensile Test Results

Weld ID	Cross-Section in x in	Fracture Load, lbs	Fracture Stress ksi (MPa)	Location
LA100	0.956 x 1.002	104,400	109.0 (752)	Base
MC100	0.948 x 1.007	102,000	106.8 (736)	Base

The above results demonstrate that the welded joints achieved 100% joint efficiency, i.e., the weld metal ultimate tensile strength exceeded the base metal tensile strength as indicated by the failure location in the base metal.

Hardness

All hardness readings were obtained on one cross-section prepared from each weld (see **Figures 1a** and **1b**) using Vicker's hardness testing equipment and a 5 kg load. The hardness traverses were performed so as to obtain the average weld metal hardness (i) at 1.5 mm subsurface location (typically 7 readings), (ii) at the root location (typically two readings), (iii) over the 10 mm lengths corresponding to the Charpy vee notch locations at the weld metal centerline (typically 5 to 6 readings corresponding to the 1.5 mm subsurface and T/2 locations). Additional indentations were placed to obtain the base material and mean maximum heat affected hardness (average of the two highest values from five indentations placed close to the fusion boundary). The results obtained are summarized in **Table 3.2**.

Face Bend Specimens

One full thickness, 6" wide surface bend specimen was prepared from each weld and sent for testing to the Dockyard Laboratories. There, a grid pattern was etched on the specimen surface before testing so that strain distribution could be estimated by periodically interrupting the bend test and measuring the grid line spacing as the specimen is progressively bent in three point bending. These measured strains at three locations of each specimen (weld metal centerline, base metal adjacent to the fusion boundary, i.e., the heat affected zone and base metal) as a function of the deflection (displacement of the load point) are shown in **Figures 3.2a, 3.2b** and **3.2c**. For comparison, the load versus deflection plots for the two welds are shown in **Figure 3.3**. The strain distributions at the outside (tensile) surface for the two specimens at the time of maximum deflection were found to be as indicated in **Table 3.3**.

Table 3.2: Hardness Traverses

Weld ID	Location	Hardness	Range
LA100	Base Metal	231	225-236
TIME Gas	HAZ	394	386-396
	WM @ 1.5 mm	276	265-299
	sub-surface		
	WM @ T/2	308	306-310
	WM @ 1.5 mm	279	268-306
	CVN notch		
	WM @ T/2	292	274-306
	CVN Notch		
MC100	Base Metal	234	225-246
Ar-2%O_2	HAZ	234	376-386
	WM @ 1.5 mm	381	268-283
	sub-surface	277	
	WM @ T/2		313-317
	WM @ 1.5 mm	314	
	CVN notch	283	
	WM @ T/2		
	CVN Notch	287	

Table 3.3: Face Bend Results

Weld	Max. Deflection (mm)	Strain % at		
		Weld Metal	HAZ	Base Metal
100S-1	39	32	50	26
MC-100	49	40	55	35

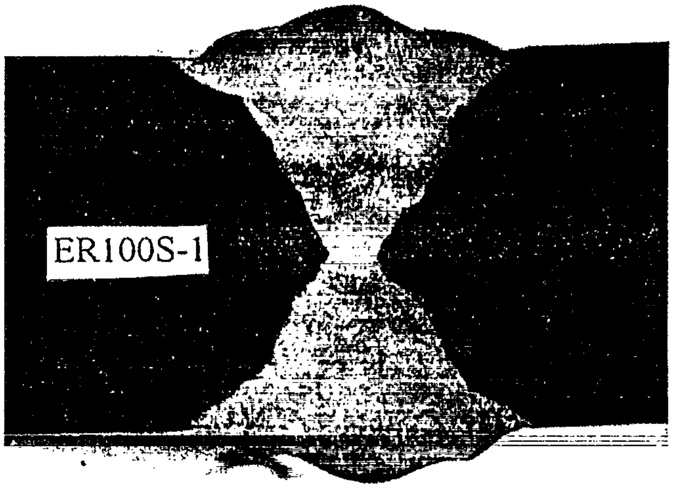


Figure 3.1a: Photomacrograph of the Cross Section of the Weld Made Using LA100 Solid Wire and TIME Gas

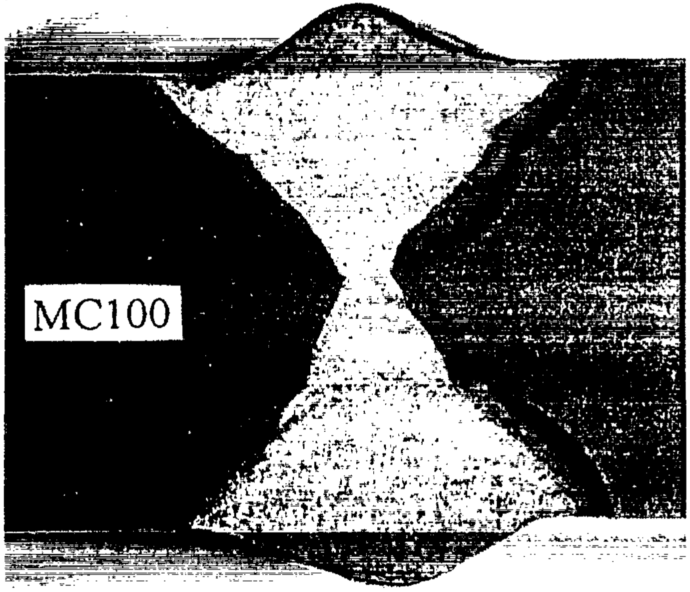


Figure 3.1b: Photomacrograph of Cross-Section of the Weld Made Using the MC-100 Metal Cored Wire and M2 Gas

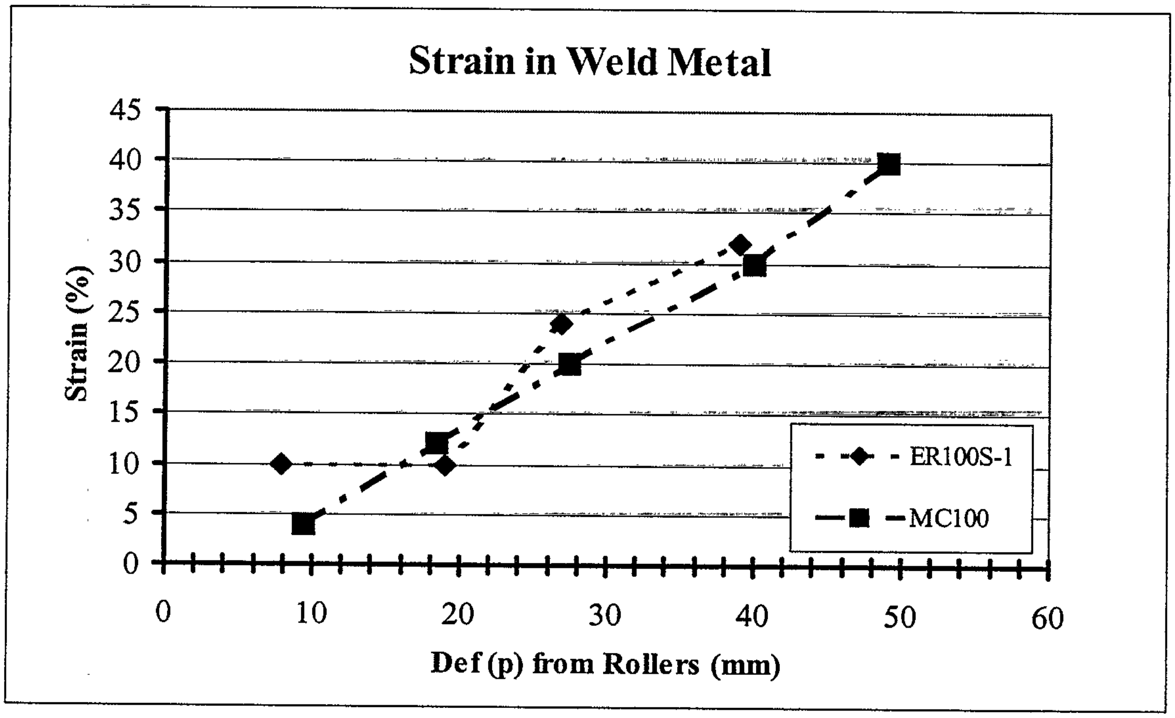


Figure 3.2a: Weld Metal Strain Versus Deflection in Bend Tests

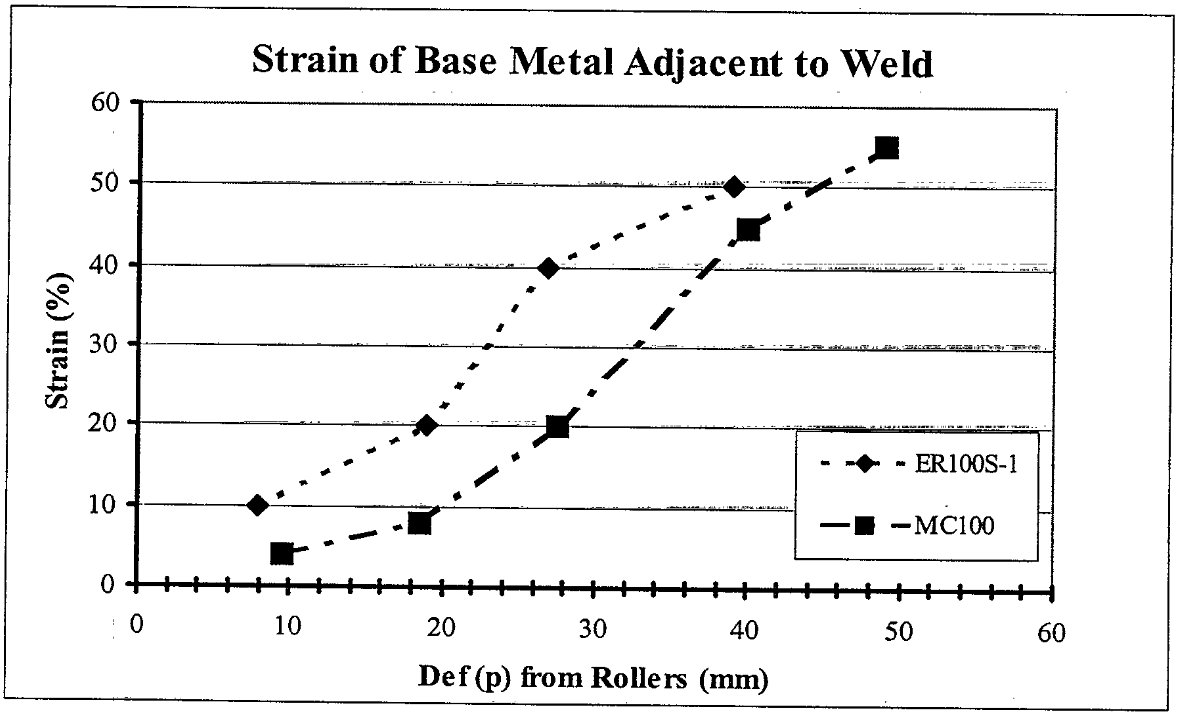


Figure 3.2b: Heat Affected Zone Strain Versus Deflection in Bend Tests

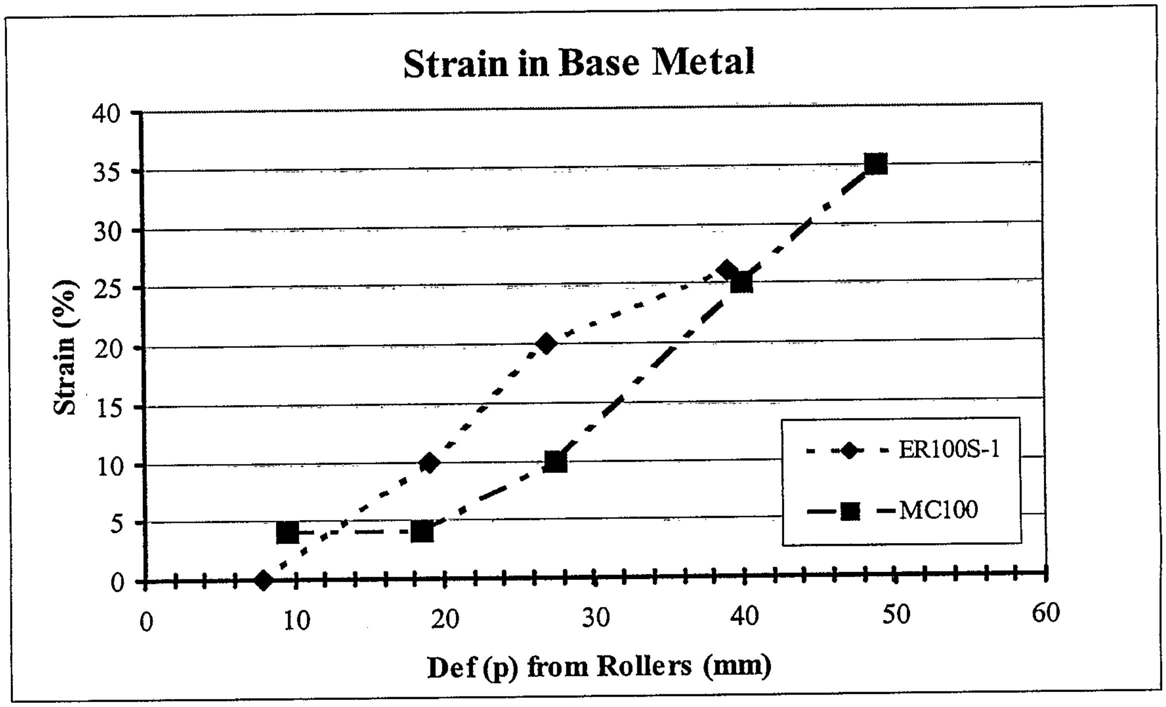


Figure 3.2c: Strain in Base Metal Versus Strain in Bend Tests

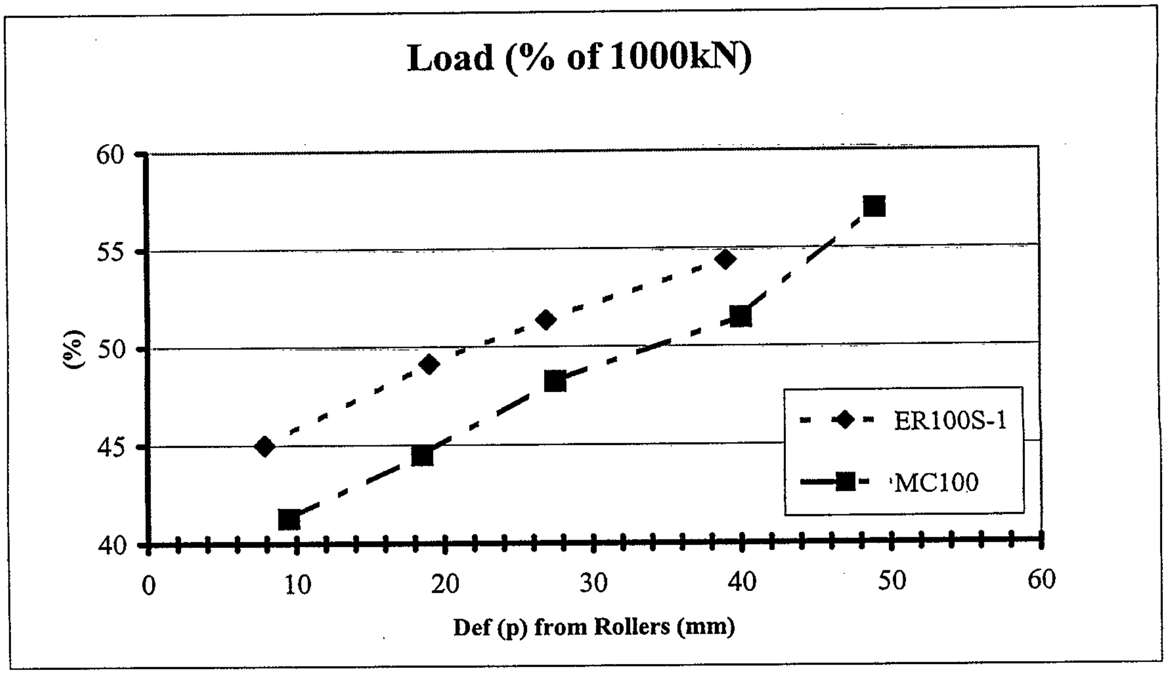


Figure 3.3: Load Versus Deflection for the Two Bend Tests

It is interesting to note that in both the specimens, the weld metal experiences higher strain than does the base metal even though the cross-weld tensile tests indicated the weld metal to have a higher ultimate tensile strength. There are two possible explanations for this.

First, in spite of a higher ultimate strength, the yield strength of the weld metal could still be lower than that of the base metal. Second, the strain distribution along the length of even a homogeneous specimen can be expected to be non-uniform, progressively decreasing as one moves away from directly under the loading point. The heat affected zone region is observed to experience the highest strain of all three locations, and this is likely due to a more complex strain state associated with the strength mis-match at the interface represented by the heat affected zone/fusion line region.

In comparing the bending behaviour of the two specimens, Figure 3.3 shows that the load required for bending the 100S-1 specimen is somewhat higher than that for the MC-100 weld. Qualitatively, this observation is consistent with the marginally higher ultimate strength and hardness of the 100S-1 weld metal. However, when the strain versus deflection plots in Figures 3.2a, 3.2b and 3.2c are examined, it is noted that the strain in the 100S-1 weld metal tends to be higher than that in the MC-100 weld metal. The same trend is applicable for the heat affected zone and the base metal. One would have expected, in principle, the same weld metal strain versus deflection plots for the two specimens.

In any case, perhaps the most important observation is that both, the weld metal and the heat affected zone/fusion line regions in both the welds could be subjected to quasi-static strains in excess of 26% without incidence of cracking or any flaw opening up.

Dynamic Tear Tests

Five nominally full thickness dynamic tear specimens were machined from each weld and notched at the weld centerline as per ASTM Standard E604. These specimens were also tested at the Dockyard Laboratories and the following results were obtained:

Table 3.4: Dynamic Tear Results

Test Temp., °C	100S-1 Weld		MC-100 Weld	
	DT Energy, J	Shear Lip, mm	DT Energy, J	Shear Lip, mm
0	1047	7.63	1279	7.43
-20	813	6.91	877	5.21
-30	757	6.48	841	5.08
-40	762	7.09	399	2.86
-47	359	3.70	239	2.60

Based on the results, it seems that a true upper shelf energy for both the welds requires a higher test temperature than the highest 0°C in the table above. Over the test temperature range employed, the 100S-1 weld could be considered to have a marginally superior toughness compared to the MC-100 weld since the dynamic tear specimens from the 100S-1 weld display higher shear lip values than the corresponding specimens from the MC-100 weld, and since the 100S-1 weld has a lower transition (≤ -40°C) compared to the MC-100 weld (between –30 and -40°C). Conversely, over the temperature range of –30 to 0°, the MC-100 weld displays slightly superior absorbed energy values. Canadian and US Military specifications require the dynamic tear energy to exceed 690 J at –29°C, and both the welds meet this requirement.

Charpy Vee Notch Toughness Tests

Up to eight CVN specimens were machined from 1.5 mm subsurface as well as T/2 location of each weld, and then duplicate specimens tested at –20°, -40° and –51°C. The absorbed energy for each specimen as well as % crystallinity is shown in **Table 3.5**.

In the case of the GMA weld, the CVN values for the T/2 location are seen to be lower than those for the subsurface specimens. The likely causes are dilution from base material and/or strain age embrittlement caused in the root region. Still, the old specification requirements of 60 ft. lbs. at –18°C and 35 ft. lbs. at –51°C are comfortably met at both locations. The new recommended toughness requirements (60 ft. lbs. at -40°C and 50 ft. lbs. at –50°C) are, however, barely met if the average value for each duplicate set of specimens is considered. Otherwise, one value of 52 ft. lbs. at -40°C fails to meet the 60 ft. lb. criterion.

As far as the weld made with the metal cored wire is concerned, it displays inferior Charpy vee-notch toughness compared to the GMA weld, likely due to the higher heat input weld passes employed in making this weld. Also, within the metal cored wire weld, the root region (T/2 specimens) displays higher toughness than does the subsurface region and this is likely due to the lower heat input (1.2 kJ/mm) of the two passes deposited in the root region from either side, compared to the fill passes (1.9 kJ/mm) and cap passes (2.4 kJ/mm). As a result, this weld meets both the old and newly recommended requirements at the T/2 location; however, at the subsurface location, it is marginal with respect to the old specification requirement as it displays 57 ft. lbs. at -20°C compared to the requirement of 60 ft. lbs. at -18°C. The new requirements are not met at the subsurface location, either at -40° or at –50°C.

The new specification is detailed in report entitled "Recommended Standard for Weld Consumable Approval System for Ships and Submarines (August 1998)" and authored by J. R. Matthews, J. F. Porter and G. R. Pelletier.

Table 3.5: Charpy Vee-Notch Results

Weld ID	Specimen Location	Test Temperature, °C	Energy Absorbed, ft.lbs.	Max. % Crystallinity
LA100		-20	102, 105	15, 15
TIME Gas	1.5 mm subsurface	-40	87, 87, 85	25, 25, 30
		-51	81, 82	20, 30
		-20	83, 86, 85	10, 15, 40
	T/2	-40	72, 52, 76	25, 30, 25
		-51	51, 61	40, 40
MC100		-20	57, 57, 53	20, 20, 50
Ar-2%O_2	1.5 mm subsurface	-40	61, 53	20, 20
		-51	35, 48, 37	40, 30, 50
		-20	64, 68, 67	10, 10, 50
	T/2	-40	69, 66	5, 10
		-51	63, 55, 58	10, 20, 25
Old Spec.		-18	60	40
		-51	35	50
New Spec.		-40	60	
		-50	50	

4. SUMMARY AND CONCLUSIONS

Two 600 mm long welds have been fabricated in HY 80 steel in the vertical up position, using respectively Lincoln LA 100 (ER100S-1) solid wire in conjunction with TIME gas and Lincoln MC-100 metal cored wire and argon-2%oxygen gas. The welding procedures used were established to ensure that the weld heat input was maintained as low as possible but consistent with the need to avoid weld flaws such as lack of fusion, trapped slag, porosity, etc.

The two welds made were indeed radiographically acceptable and free of any crack-like flaws. However, the average weld heat input per pass was roughly twice as high for the metal cored wire weld (1.83 kJ/mm) as for the solid wire gas metal arc weld (0.89 kJ/mm), and because of the reduced wettability and wide weave required with the metal cored wire in conjunction with M2 gas, the procedure/process can be considered to be lacking in user friendliness. (It is likely that in the flat, horizontal and overhead positions, especially if a shielding gas other than M2 is used, lower heat input, stringer beads can be deposited which could provide weld metal with greater toughness than observed in this investigation.)

In spite of the differences in heat input and pass sequence, the weld metal hardness was similar for both the welds. The main effect of the lower heat input seems to be that mean maximum HAZ hardness was marginally higher for the solid wire weld, 394 HV_5 versus 381 HV_5 for the metal cored wire weld.

Still, the higher HAZ hardness did not cause any problem in the wide bend tests as the specimens were successfully subjected to three point tests with the strain exceeding 30% in weld metal and 50% at the fusion boundary. Both the welds also achieved 100% joint efficiency.

As far as the weld metal toughness is concerned, the Charpy veenotch results strongly indicate that the weld metal toughness of the 100S-1 solid wire weld is superior to that of the MC-100 wire weld, however, this might be debatable for the T/2 location at low test temperature. The respectable toughness of the metal cored wire weld at the T/2 location is believed to be the result of limited strain age embrittlement at this location in this weld due to the reduced number of passes, a feature that also makes the procedure less user friendly.

This reasonably adequate toughness in the root region could also be responsible for adequate dynamic tear toughness performance of the metal cored wire weld where the fracture path samples the entire range of microstructures through the thickness and the total absorbed energy may be influenced to a greater extent by the toughness in the middle one third of the thickness rather than the outer 1/3rd of the thickness. Consequently, while the metal cored wire weld displayed somewhat higher absorbed energies over the temperature range –30° to 0°C, the shear lip values and transition temperature were superior for the solid wire weld.

In conclusion,

- Benchmark welding procedures (lowest possible heat input consistent with sound welds) have been developed for groove welds in the vertical position in HY 80 steel using two consumable combinations, viz., Lincoln LA100 (ER100S-1) solid wire with TIME shielding gas, and Lincoln MC-100 metal cored wire with M2 shielding gas;
- the solid wire procedure is preferred over the metal cored wire – M2 gas procedure, as the latter requires wide weave, slow travel speed and overall greater welder skill;
- Notwithstanding the above drawback, sound welds could be deposited with each consumable combination that achieved 100% joint efficiency and excellent ductility as indicated by greater than 30% strain in the full thickness, wide face bend specimens;
- From the weld metal notch toughness standpoint, both the welds met the 690 J dynamic tear energy at –29°C. The metal cored wire weld had slightly superior toughness at temperatures greater than –29°C, however, the solid wire weld had a lower ductile to brittle transition temperature. When assessed in terms of the Charpy vee-notch energy, the solid wire weld demonstrated an overall superior notch toughness.

APPENDIX A

Welding Procedure Data Sheets

FLEET TECHNOLOGY LIMITED

Welding Procedure Data Sheet

WPS No.: HY80-100S1-1

WPDS No.: FTL-HY80-3G-PGMAW-1

Welding Process: Pulsed GMAW

Filler Metal Classification: ER 100S-1

Material Specification: HY-80

Preheat Temperature (°C): 90

Interpass Temperature (°C): 120

Preheat Method: Torch

Position of Welding: 3G Travel Direction: UP

Polarity: DCEP

Shielding Gas: TIME 26.5%He, 8%CO_2, 0.5%O_2, Ar Bal

Flow Rate (l/min): 25

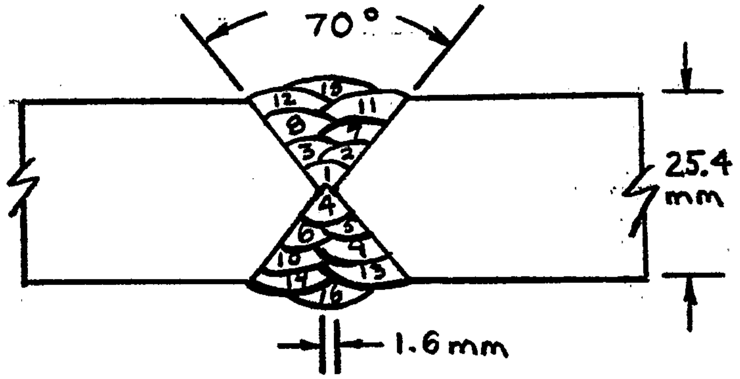
Nozzle Orifice Size (mm): 15

Manual, Semi-Auto, Auto: Semi-Auto

Single or Multiple Arc: Single

Single or Multipass: Multipass, temper bead technique

Root Treatment: Backgrind, 2mm depth



Weld Sequence			Electrode Size		Wire Feed Speed		Amps	Volts	ESO		Travel Speed		Heat Input	
Side	Layer	Pass	mm	in's	mm/min	in/min	A	V	mm	in's	mm/min	in/min	kJ/mm	kJ/in
1 & 2	1	1 & 4	1.2	.045	3555	140	115	19.2	12	0.5	161.8	6.4	0.82	20.8
1 & 2	2	2 & 5	1.2	.045	3555	140	118	20.4	12	0.5	226.5	8.9	0.64	16.3
1 & 2	2	3 & 6	1.2	.045	3555	140	120	20.6	12	0.5	168.8	6.6	0.88	22.4
1	3	7 & 8	1.2	.045	3555	140	110	21	12	0.5	141.9	5.6	0.98	24.9
2	3	9 & 10	1.2	.045	3050	120	105	21	12	0.5	162.3	6.4	0.82	20.8
1	4	11 & 12	1.2	.045	3430	135	107	21	12	0.5	135.2	5.3	1.00	25.4
2	4	13 & 14	1.2	.045	3430	135	107	21	12	0.5	135.2	5.3	1.00	25.4
1	4	15	1.2	.045	3430	135	107	21	12	0.5	135.2	5.3	1.00	25.4
2	4	16	1.2	.045	3430	135	107	21	12	0.5	135.2	5.3	1.00	25.4

Procedure Qualification Record No.: N.A.

Approval:

FTL:

Procedure Notes:

- Torch Angle: 15° inclined.
- Interpass Cleaning: Power stringer wire brush.
- Temperature Monitoring: Calibrated thermalcouples.

Date: January 8, 1999

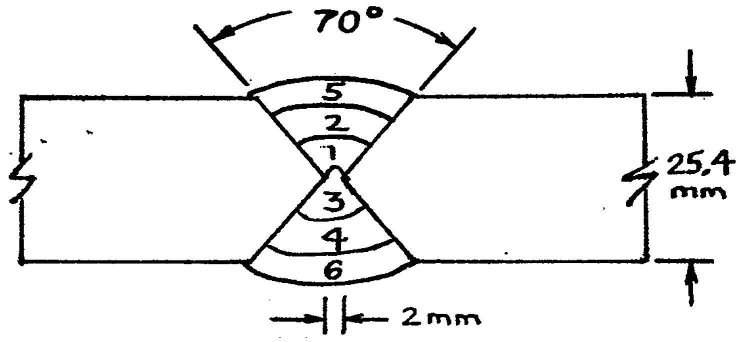
FLEET TECHNOLOGY LIMITED

Welding Procedure Data Sheet

WPS No.: HY-80-MC100-1

WPDS No.: FTL-HY80-3G-PMCAW-1

Welding Process:	PMCAW
Filler Metal Classification:	MC-100
Material Specification:	HY-80
Preheat Temperature (°C):	90
Interpass Temperature (°C):	120
Preheat Method:	Torch
Position of Welding:	3G Travel Direction: UP
Polarity:	DCEP
Shielding Gas:	M2; 2%0_2 Ar Bal Flow Rate (l/min): 25
Nozzle Orifice Size (mm):	15
Manual, Semi-Auto, Auto:	Semi-Auto
Single or Multiple Arc:	Single
Single or Multipass:	Mulipass
Root Treatment:	Backgrind, 2 mm depth



Weld Sequence			Electrode Size		Wire Feed Speed		Amps	Volts	ESO		Travel Speed		Heat Input	
Side	Layer	Pass	mm	in's	mm/min	in/min	A	V	mm	in's	mm/min	in/min	kJ/mm	kJ/in
1	1	1	1.2	.045	5845	230	146	20.3	12	0.5	147	5.8	1.2	30.5
1	1	2	1.2	.045	6350	250	148	21.2	12	0.5	99	3.9	1.9	48.3
2	1	3	1.2	.045	5845	230	138	20.3	12	0.5	137	5.4	1.2	30.5
2	2	4	1.2	.045	6350	250	148	21.2	12	0.5	99	3.9	1.9	48.3
1	3	5	1.2	.045	6350	250	148	21.5	12	0.5	79	3.1	2.4	60.9
2	3	6	1.2	.045	6350	250	148	21.5	12	0.5	79	3.1	2.4	60.9

Procedure Qualification Record No.: N.A.

FTL:

Procedure Notes:

- Torch Angle: 15° inclined
- Interpass cleaning: Grinding and power stringer wire brush
- Temperature Monitoring: Calibrated thermalcouples

Date:
January 8, 1999

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Previous investigations carried out at DREA and on its behalf have demonstrated that the gas metal arc welding (GMAW) process using selected electrode wires and shielding gases provides superior weld metal toughness in submarine steels than is the case for the shielded metal arc welding process.

More recently, a past project demonstrated that pulsing power source technology had advanced to a state where GMAW welds should be reliably produced at low enough heat inputs to provide good weld metal toughness and avoid the lack of fusion flaws which have been commonly associated with previous attempts.

Two welded panels were produced using different wire/gas combinations; one of which had shown considerable promise in previous DREA investigations (LA 100/TIME) and the other having shown great potential in manufacturer's technical literature (MC-100/M2). Radiography at +/-20° to normal revealed no objectionable discontinuities and no lack of fusion.

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Pulsed GMAW
GMAW
TIME Welding
Upholder
Dynamic Tear

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