#510306 ①

The DREA Welding Program 1980-1993

by

J. R. Matthews

Defence Research Establishment Atlantic
FMO Halifax, Halifax Nova Scotia B3K 2X0

Abstract

From 1980 to 1993 DREA Dockyard Laboratory supported an extensive research program in welding processes for HY steels. This program was begun in long term anticipation of the Canadian Navy replacing the Oberon submarines and the need for extensive Canadian knowledge in fabrication and inspection with HY steels. In later years this program has found more immediate application in questions related to extension of Oberon life, ie cladding, mismatched steels, electrode substitution and certification etc. The welding program has included many types of welding, all position, numerous equipment and consumable types, different gases, a range of heat inputs etc. Several novel Canadian processes have been explored in addition to traditional welding methods. After considerable welding and evaluations, numerous procedures have been developed using different processes, and an optimized pulsed GMAW process has been identified that provides properties approaching those of HY steels.

Introduction

In the past twelve years DREA/DL has supported extensive research in welding processes for HY steels. We have examined SMAW (shielded metal arc welding), SAW (submerged arc welding), GMAW (gas metal arc welding), FCAW(flux cored arc welding), and laser assisted arc welding. Processes were examined to new specifications and requirements developed in parallel with the welding (ie dynamic tear and explosion bulge). Efforts were made to isolate those processes most suitable for shipyard work and most capable of routinely producing properties approaching HY steels. In addition to development of optimum procedures for standard processes, DREA isolated two Canadian welding processes that have proved outstanding. The first is frequency modulated pulsed GMAW and the second is TIME (transfer ionized molten energy) GMAW welding. In 1988 to 1990 these two processes were evaluated in a very complete 24 weldment series comparison. This resulted in identification of pulsed welding with Fronius equipment and TIME welding as the two most outstanding processes. In the past year four additional weldment series were made using a combination of these two processes. (Fronius developed special pulsed equipment for use with TIME.)

We will first give a brief background to welding of QT 28 and HY steels before outlining welding research conducted in the past twelve years in detail.

Background

In the late 1960's Canada purchased three Oberon submarines from the UK. Engineering and ship repair support had to come to full speed immediately in the areas of maintenance, repair, supply and alterations. This required immediate development of Canadian welding, inspection and supply of materials for the fabrication aspects of the job. The UK was the main source of supplies, in particular QT 28 steel and Fortrex B welding electrodes. The UK exchanged an engineering officer to work in NEU providing engineering support, on an ongoing basis from the late sixties scheduled to stop in the near future(1993/94). Specifications were provided for welding (DG Ships 240), inspection (DG Ships 9022) and acceptance (DG Ships 10000).

DREA/ Dockyard Laboratory's role in the early stages, late 60's to 1980, focused on engineering and technical support. Dockyard Lab provided early NDT including MPI, Ultrasonics and Radiography for the submarine work, and also technical support in establishing inspection requirements and actually providing for inspection and records (ie heat treat, root pass, back pass, temper bead, weld profile inspection, NDT coordination, production of records and certification). Dockyard Lab was involved in welder qualification, consumable qualification and procedure qualification, especially the acceptance and record keeping aspects.

In 1980, roles changed with creation of the Welding Inspector/Officer position at NEU aimed at taking over the inspection and record keeping aspects from DREA as well as responsibility for procedure qualification and welder qualification. Dockyard Lab retained responsibility for radiography (SRU established an NDT group to perform MPI/LPI, UT and all other forms of inspection around 1975), welding engineering consulting and certification of welders.

The main focus of DREA then switched to research of welding, inspection and weldment acceptance(explosion and fracture testing). To that point welding was still restricted to SMAW welding with Fortrex B electrodes. Acceptance of weld procedures and new consumables was believed to be possible with charpy and bend bar testing, and NDT was limited to standard industrial RT and UT. The weld acceptance criteria were very strict.

The main focus of this paper is to look at the research done in the past 12 years on welding processes that would give workmanship advantages over SMAW, but that would also provide properties approaching HY steels. In separate reports we explore the research work done to develop intelligent automated ultrasonic inspection. The intelligent automated inspection was required to permit identification and mapping of the various types of weld defects to allow condemnation criteria based on specific defect type. Finally, fracture research has focused on introduction of minimal testing requirements for procedure and consumable qualification. That work has established DT levels of 690 joules at -29C and 16 % strain in explosion bulge for HY80 and 12% for HY 100 as minimal acceptance levels. Fracture work has also focused on elastic plastic research and fracture control technology.

Welding research has been assisted greatly by contracts with many organizations, all of whom will be acknowledged and referenced in this report. The series of CF/CRAD Meetings on Research in Fabrication and Inspection of Submarine Pressure Hulls[1,2,3,4] has provided a forum for exchange of ideas between CF engineers, scientists, contractors and international welding specialists. International cooperation in this area has been fostered by two operating assignments in TTCP P(Materials) TP1(Metals); specifically an assignment on Welding HY80[5,6,7] and an assignment on Fracture Control for Naval Structures. Finally, NDHQ has started(1990/91) development work in producing a Canadian Steel and Welding Procedures for an HYW700QT steel.

We will continue this report by outlining the specific welding research that has been carried out.

Welding

Several overviews have been given over the years including those at the CF/CRAD Conferences[8,9,10] and the Defence Science Symposium[11]. The following overview will be divided according to welding process type. Table 1 gives a brief summary of the welding

Table 1. Welding Research at DREA 1980-1993

Shielded Metal Arc Welding (SMAW)

ELECTRODE	STEEL	
E7018	HY 80	SRUA
E9018M	HY 80	SRUA
Fortrex B	HY 80 and QT 28	SRUA
E11018M	HY 80	SRUA
E12018M2	HY 100	HDIL

Submerged Arc Welding (SAW)

HEAT INPUT	STEEL	
1.5kJ	HY 80	Versatile Vickers
2kJ	HY 80 HY 100 and HSLA 80	MTL (CANMET)
3kJ	HY 80 HY 100 and HSLA 80	MTL (CANMET)
4kJ	HY 80 HY 100 and HSLA 80	MTL (CANMET)

Gas Metal Arc Welding (GMAW)

a. T.I.M.E. (transfer ionized molten energy)

WIRE	JOINT	STEEL
LA 100	narrow gap	HY 80 Techno Sci
LA 100 Linde 95 Linde 120	double vee	HY 80 Weld Process/Techno Sci
LA 100 Linde 120	double vee	HY 80/100 Fleet/Weld Proc

b. Pulsed

MACHINE	STEEL	
Generac(Japan)	HY 80/100	WIC
Hobart(US)	HY 80/100	WIC
WIC/FM(Can)	HY 80/100	Fleet/WIC
TP Fronius(Austria)	HY 80/100	Fleet/WIC/Weld Proc

Flux Cored Arc Welding (FCAW)

	HY 80/100	TUNS

Laser Assisted Gas Metal Arc Welding — Laser Institute including the essential variables. In the early years the focus was HY 80 but in later years HY 100 was included in all work.

i. Shielded Metal Arc Welding (SMAW)

Welding for base line testing[12,13,14,15] in shielded metal arc welding was conducted at Ship Repair Unit Atlantic(SRUA) using procedures developed for work on Oberon submarines. The electrodes and steels evaluated are shown in Table 1. From this work electrodes available in North America suitable for replacement of Fortrex B were identified.

When interest in HY100 began we received advice from DTRC and DRA Dunfermline about the most promising stick electrodes and contracted HDIL to produce weldments for further base line testing.[16] The E12018-M2 electrodes were obtained from Alloy Rods in Hanover, Pa. Preheat and interpass temperatures were controlled in the usual way. Despite excellent quality welding the impact results (as predicted by DTRC and DRA Dunfermline) did not meet the required 690 joules at -29C. It was thus verified that any fabrication with HY 100 would require at least a semi-mechanical process.

ii. Submerged Arc Welding (SAW)

Research work in submerged arc welding was conducted at CANMET. Most welding was done in house but some was done in the ship yards at Versatile Vickers. Heat input was the major variable studied by CANMET. Values of 1.5 kJ, 2 kJ, 3 kJ and 4 kJ were evaluated for HY 80, HY 100 and HSLA 80 steels.[17,18] CANMET has a broad range of expertise in this area developed over a considerable period of time.

iii. Gas Metal Arc Welding (GMAW)

a. T.I.M.E. (transfer ionized molten energy)

In an effort to acquire all-position semi-mechanical welding for HY80 steel plate, several welding processes including those employing novel gas mixtures for gas metal arc welding have been studied. T.I.M.E.(transfer ionized molten energy) process from Weld Process International has been evaluated the most by DREA due to superb early results.[19,20,21]

The T.I.M.E. process[22,23] was developed in 1980 after many years of research and development of gas mixtures for shielding and metal transfer. The process is a gas metal arc welding process which employs a special gas, Table 2, and a specially designed nozzle.

Table 2. Composition of TIME Gas

gas	Ar	CO_2	He	O_2
T.I.M.E. 1	65	8	26.5	0.5

The process produces welds that are very clean with reduced sulfur and phosphorous levels and enhanced weldment toughness. It is believed that the reduced impurities are responsible for the improved toughness of the weldments. The transfer characteristic is effective in the short arc mode as well as the globular and spray modes. The welding in this work was all conducted in the spray arc mode.

In 1988, welding procedures were developed for the four positions of interest- flat, horizontal, vertical down and overhead, Table 3, using standard welding machines.[21,24]

Table 3. Welding Procedures for the Four Positions[21,24] (all spray transfer)

Welding Parameters	Flat	Horizontal	Vertical Down	Overhead
Wire Diameter (mm)	1.14	1.14	1.14	1.14
Tip Recess (mm)	2.5 - 3	2.5	2.5	2.5
Stick Out (mm)	12 - 16	12 - 16	12 - 16	12 - 16
Shield Gas	T.I.M.E.	T.I.M.E.	T.I.M.E.	T.I.M.E.
Gun Type (T.I.M.E.)	Watercooled	Watercooled	Watercooled	Watercooled
Angle of Gun	45	45	75	45
Plate Thickness (mm)	25	25	25	25
Gap (mm)	2.5	2.5	2.5	2.5
Included Angle	50	50	50	50
Wire Speed (m/min)	8.8	8.9	8.9	8.4
Amps	220	240	240-245	200-220
Volts Root Pass	29	26.5	26.5	29
Volts Subsequent Passes	30	27	29.5	27.5
Travel Speed Root Pass (mm/min)	337	450	450	337
Travel Speed Subsequent Passes	450	600	800	600
Heat Input Root Pass (kJ/mm)	1.14	.88	.85	1.1
Heat Input Subsequent Passes (kJ/mm)	.88	.65	.54	.61

At that time(1988), the welds were evaluated for impact and explosion resistance. 16 mm dynamic tear tests were carried out. These tests indicated the tearing resistance of the weldments for direct comparison to the performance of each other and the parent plate. Specimens were cut from weld metal and heat affected zones of the welded plates. The heat affected zone samples had the notches located in the space between the fusion line and 1 mm from the fusion line in the centre of the plate. The specimens were tested at -29^{o}C. Shear index was determined for each DT sample. The dynamic tear results were in the normal range with a Linde 95 wire (650 J) but were much higher with a Lincoln LA 100 wire(1300 J). It was felt that the TIME gas had an enhancing effect on the toughness result for all welds while incomplete fusion defects had a detrimental effect for the Linde 95 Welds. Our net experience suggests that LA 100 wire should be utilized in the production welding of HY80 steel plate when weld toughness equal to the plate (T-L orientation) is required. All the samples passed the explosion bulge test.

Subsequent to the work completed in 1988 a weld study involving TIME and pulsed welding was carried out by Fleet Technology, TIME Weld Process, and WIC[25,26]. 24 weldments were prepared for HY80 and HY100 with a variety of machine gas combinations.

In 1992/93 a final weld series was carried out with the TIME process on HY80/100 using specially designed pulsed welding equipment from Fronius. This work has resulted in final recommendations for weld procedures using the TIME process.[27]

b. Pulsed GMAW

The earliest studies of pulsed welding supported by DREA were with WIC[28,29,30]. WIC had patented a frequency modulated pulsed welding system that relied on voltage feedback and frequency modulation of identical pulses, to compensate for required rate of metal transfer. This was different from synergic pulsed systems which used variable speed wire feed to compensate for rate of metal transfer requirements.

Studies involved comparisons of the WIC system to early commercial pulsed systems such as Generac[29] and Hobart[30], and later to TP Fronius[25,26], Table 4.

Table 4. Pulsed Welding Equipment Evaluated

MACHINE	STEEL	CONTRACTOR
Generac(Japan)	HY 80/100	WIC
Hobart(US)	HY 80/100	WIC
WIC/FM(Can)	HY 80/100	Fleet/WIC
TP Fronius(Austria)	HY 80/100	Fleet/WIC/Weld Proc

Unfortunately, despite early success in welding the HY steels[28,29,30], the commercial version of the WIC FM system was optimized around an .035 wire and was not suitable for the HY steels.[25,26]

Pulsed welding of HY80/100 with C5 gas and Fronius equipment remains one of the best performers to date.[25,26] This was a major contributing factor to TIME Weld Canada's having teamed up with Fronius to produce pulsed equipment optimized for the TIME gas.[27]

iv. Flux Cored Arc Welding (FCAW)

Work in Flux Cored Arc Welding for DREA was conducted by Keith Leewis, TUNS. Basic research in fluxes[33] was very successful but application of FCAW to HY80/100 was not.[34,35,36] The effort here was minimal.

v. Laser Assisted Gas Metal Arc Welding

Work in laser assisted GMAW at the Laser Institute has been progressing steadily for the last few years.[37] We hope to explosively test some of these welds in 1993.

Evaluations

In the welding section above general comments on the success of the various welding was summarized focusing on dynamic tear and explosion bulge highlights.

For more detailed information on these evaluations including information on fracture, fatigue and corrosion fatigue testing see the final references in this report.[38-50]

Conclusions

Semi mechanical welding for use on submarine pressure hulls have been successfully developed in the past twelve years under the DREA welding program.

Several welding procedures exhibit impact properties approaching those of HY Steels.

Optimum welding procedures for GMAW of HY80/100 using the TIME welding process have been determined.

References

General

1. J.R. Matthews, "Abstracts and Summaries of the lst Canadian Forces/CRAD Meeting on Research in Fabrication and Inspection of Submarine Pressure Hulls, Halifax, Nova Scotia, May 28-29, 1985.

2. J.R. Matthews, "Abstracts and Summaries of the 2nd Canadian Forces/CRAD Meeting on Research in Fabrication and Inspection of Submarine Pressure Hulls", Halifax, Nova Scotia, May 26-28, 1987.

3. J.R. Matthews, " Abstracts and Summaries of the 3rd CF/CRAD Meeting on Research in Fabrication and Inspection of Submarine Pressure Hulls", Halifax, Nova Scotia, June 6-8, 1989.

4. J.R. Matthews, " Abstracts and Summaries of the 4th CF/CRAD Meeting on Research in Fabrication and Inspection of Submarine Pressure Hulls", Halifax, Nova Scotia, June 4-6, 1991.

5. J.R. Matthews, "TTCP Operating Assignment - Welding of HY 80 Steel," TTCP P-TP1/CAN/2/86, January 1986.

6. J.R. Matthews, "1987 Progress Report on Welding of HY Steel", PTP1/CAN/2/88, March 1988.

7. J. Bird, J.R. Matthews et al, "Welding of HY 80 Steels", Technical Panel Assignment TTCP-P-TP1 Final Report, prepared by ARE(D) on behalf of NSRDC(Annapolis), DREA(Halifax) and MRL(Melbourne), PTP1/1/89, August 1989.

8. J.R. Matthews, "General Introduction to Shielded Metal Arc Welding (SMAW) on Oberon Class Submarines," Abstracts and Summaries of the CF/CRAD Meeting on Research in Fabrication and Inspection of Submarine Pressure Hulls, May 1985.

9. J.R. Matthews, "General Introduction to Shielded Metal Arc Welding (SMAW) on Oberon Class Submarines," Abstracts and Summaries of the 2nd CF/CRAD Meeting on Research in Fabrication and Inspection of Submarine Pressure Hulls, Halifax, N.S., May 26-28, 1987.

10. J.R. Matthews, "The DREA Submarine Welding Program 1980-1990", in abstracts and summaries of the 4th CF/CRAD Meeting on Research In Fabrication and Inspection of Submarine Pressure Hulls, Halifax, Nova Scotia, June 4-6, 1991.

11. J.R. Matthews, "Research on Fabrication and Inspection of Submarine Pressure Hulls," presented at Defence Science Symposium, Ottawa, April 1988.

Shielded Metal Arc

12. J.R. Matthews and K.J. Allen, "JId and Dynamic Tear of HY80 Weldments," presented at the 1st CF/CRAD Meeting on Research In Fabrication and Inspection of Submarine Pressure Hulls, May 1985.

13. J.F. Porter and J.R. Matthews, "Explosion Bulge Evaluation of SMAW and Narrow Gap Weldments,"presented at the 1st CF/CRAD Meeting on Research In Fabrication and Inspection of Submarine Pressure Hulls Ibid, May 1985.

14. J.F. Porter and J.R. Matthews, "Explosion Bulge Behavior of SMAW and Narrow Gap Weldments of HY 80," DREA RN/DL/85/6, September 1985.

15. J.R. Matthews and K.J. Allen, "Toughness of HY 80 SMAW and Narrow Gap Weldments Using J-Integral and Dynamic Tear," DREA RN/DL/85/3, April 1985.

16. R.M. Robichaud and I.M. Campbell, "Shielded Metal Arc Welding of HY100 Steel Plate with E12018M2 Electrodes", Halifax Dartmouth Industries Ltd., DREA CR/87/444, October 1987.

Submerged Arc

17. J.T. Bowker, M.W. Letts, J.A. Gianetto and R.F. Orr, "An Evaluation of the Notch Toughness of the Heat Affected Zone in HY and HSLA Steel", CANMET, DREA CR/87/451, October 1987.

18. J.T. McGrath, J.A. Gianetto and R.F. Orr, "A Comparison of the Microstructural and Mechanical Properties of Submerged Arc Welding in HY80 and HSLA80 Steels", CANMET, DREA CR/87/450, October 1987.

TIME

19. M.Macecek and J. Belbeck, "Narrow Gap Welding of HY80 Steels Using the TIME Process", Techno Scientific Inc., DREA Contractor Report, 1983.

20. M. Macecek and J. Belbeck, "Research in Narrow Gap Welding", Techno Scientific, DREA/CR/86/434, April 1986.

21. M.Macecek, "All Position Welding of HY80 Plate with the TIME Process", Techno Scientific Inc., DREA CR/88/419, 1988

22. Rodwell, M.H., "Evaluation of the T.I.M.E. MIG Welding System", Project Report LD22983/1/83, The Welding Institute, Cambridge U.K., October 1983

23. "Welding Characteristics of a new welding process, T.I.M.E. Process", prepared by the Aichi Sangyo Co. Ltd., Japan, July 1989

24. J.R. Matthews, J.F. Porter, J. Church, M. Macecek "An Evaluation of T.I.M.E. Welding of HY80 Plate," The Welding Journal,70, February 1991.

25. L. Malik, K.G. Morrison and L.N. Pussegoda, "All Position Gas Metal Arc Welding of HY80 and HY100 Steels, prepared by Fleet Technology Limited, contractor report, DREA CR/91/434, May 1991.

26. L. Malik, K.G. Morrison, L.N. Pussegoda and J.R. Matthews, "All Position GMAW Welding of HY80 and HY100 Steels", in abstracts and summaries of the 4th CF/CRAD Meeting on Research In Fabrication and Inspection of Submarine Pressure Hulls, Halifax, Nova Scotia, June 4-6, 1991.

27. R.M. Robichaud, "Evaluation of TIME Weld Procedures Optimized for HY80/100 Steels Using Specially Designed Fronius Welding Equipment", Donelad Ltd., DREA Contractor Report, 1993 (in edit)

Pulsed

28. A. Ditschun, "Application of Pulsed Current Techniques to Welding HY80 Steel", Welding Institute of Canada, DREA Contractor Report, 1984.

29. A. Ditschun, "Application of Pulsed Current Techniques to Welding HY80 Steel", Welding Institute of Canada, DREA Contractor Report, CR 85/421, September 1985.

30. E. Lassaline, "Application of Pulsed Current Techniques to Welding HY80 Steels", Welding Institute of Canada, DREA CR/887/405, 1987

31. J.R. Matthews, E.E. Lassaline, J.F. Porter, and K.G. Leewis, "Evaluating Frequency-Modulated GMA Welding for HY80 Steel", The Welding Journal, 71, September 1992.

32. J.R. Matthews, E.E. Lassaline, J.F. Porter, and K.G. Leewis, "An Evaluation of Pulsed Gas Metal Arc Welding for HY80 Steel," DREA RN/DL/93/1 , January 1993.

Flux Cored

33. K. Leewis, "Surface Tension Effects in the Flux Cored Arc Welding of HY80 Steels", TUNS, DREA CR/87/462, December 1987.

34. K.G. Leewis, "Flux Cored Welding for HY80/100 Steels", TUNS, DREA CR/89/432, Oct 1989.

35. K.G. Leewis and J.R. Matthews, "Qualification of a FCAW Consumable for HY 80 and HY 100 Steels", presented at the 3rd CF/CRAD Meeting on Research In Fabrication and Inspection of Submarine Pressure Hulls, June 1989.

36. M. Pineo, K.G. Leewis, and J.R. Matthews, "Flux Cored Welding of HY 80 and HY 100", presented at the 28th Annual Conference of Metallurgists, Halifax, August 1989.

Laser

37. K.H. Magee, V.E. Merchant and C.V. Hyatt, "Laser Assisted Gas Metal Arc Weld Characteristics", Laser Materials Processing, Vol. 71, 1991, 382-399.

Fracture, Fatigue and Corrosion Fatigue

38. T. Betancourt, "Corrosion Fatigue Crack Growth Behaviour of HY80 SMAW and Narrow Gap Weldments", NSRFC, DREA Contractor Report, CR/85/406, April 1985.

39. A. Kazi, "Effect of Welded Residual Stress on Fatigue Life of HY80 Plate", NSRFC, DREA Contractor Report, 1984.

40. T. Betancourt, "Corrosion Fatigue Crack Growth Behaviour of Shielded Metal Arc Weldments and Metal Inert Gas Weldments", NSRFC, DRREA CR/86/427, April, 1986.

41. A. Kazi, "Effect of Weld Stress on the Fatigue Life of HY80 Plate", NSRFC, DREA CR/87/417, March 1987.

42. T. Betancourt and M. Robichaud, "Study of Corrosion Fatigue Crack Growth Behaviour of Shielded Metal Arc Weldments and Metal Inert Gas Weldments", NSRFC, DREA CR/89/411, April 1989.

43. M.N. Bassim, "High Strain Rate Impact Study of Submarine Pressure Hull Weldments", University of Manitoba, DREA contractor Report, CR/86/404, March 1986.

44. M.N. Bassim, "High Strain Rate Impact Study of Submarine Pressure Hull Weldments", Univ of Manitoba, DREA CR/89/404, Feb 1989.

45. M. Nabil Bassim, "Determination of the Dynamic Fracture Toughness of Submarine Hull Weldments", DREA Contractor Report CR/92/423, April 1992

46. J.R. Matthews, K.J. Allen, and G.I. Dease, "Dynamic Tear of HY 80 Weldments," DREA RN/DL/86/1, January 1986.

47. J.R. Matthews and G.I. Dease, "Dynamic Tear of HY80, HSLA80 and HY100 Weldments," DREA Research Note DL/88/1, January 1988.

48. J.R. Matthews, G.I. Dease and R. LeTourneau, "Dynamic Tear and Shear Index for GMAW Weldments of HY 80 and HY 100", DREA Research Note, DL/91-1, Jan 1991.

49. J.F. Porter, D.O. Morehouse, J.R. Matthews, "Response of SMA and Narrow Gap HY80 Weldments to Explosive Shock Loading," DREA Technical Memorandum 88/206, March 1988.

50. J.R. Matthews, "On the Relationship Between Shear Index and Energy in Dynamic Tear Specimens," submitted to Engineering Fracture Mechanics.