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EFFECT OF ZINC-BEARING PRIMERS ON THE MANUAL METAL-ARC WELDING OF CSA G40.8 GRADE B STEEL

by

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PHYSICAL METALLURGY DIVISION

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SPONSORSHIP

This investigation was undertaken as the result of a request from the Royal Canadian Navy as detailed in a letter from the Deputy Minister, Department of National Defence, to the Deputy Minister, Department of Mines and Technical Surveys, dated February 4, 1965 (File: NS7051-550 (DG Ships)), and elaborated in discussions preceding and following this communication between representatives of the research and technical staff of the two Departments.

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INTRODUCTION

This investigation relates to quick-drying primers for application to abrasive-blast cleaned steel prior to fabrication. These primers are required to protect the steel before and after fabrication or until such time as the steel can be overcoated with an appropriate paint system. The manufacturers claim that these primers do not interfere with welding operations or the weld quality. It is the substantiation or otherwise of this latter claim that constitutes the purpose of the present investigation.

Four different types of primer have been identified in a program of work now being undertaken at the British Welding Research Association[1]:

(a) Zinc-rich organic bound (epoxy)
(b) Zinc-rich inorganic (silicate)
(c) Aluminum-rich (epoxy)
(d) Iron oxide.

There are a large number of these primers commercially available. The Ship Department, Ministry of Defence (U.K.) refers[2] to an approved list of 34 primers under Specification D.G. Ships/PS/9004A. Apart from their wide use in the U.K., similar products are being used in the U.S.A. and Canada.

The more detailed purposes of the present investigation may be described as follows:

(a) To assist the Royal Canadian Navy in formulating its attitude to the use of such products in the fabrication of naval vessels in Canadian dockyards.

(b) To assist the Royal Canadian Navy in the assessment of the welding quality of vessels fabricated by U. K. dockyards, where such products were used, both in connection with the original welding and in subsequent repair operations at Canadian dockyards.

PREVIOUS WORK

A short investigation[3] was carried out on a commercial primer by the Physical Metallurgy Division in 1961. Bead-on-plate welds were made on 3/8 in. thick steel plate on shot-blasted and on shot-blasted and primed surfaces. The primer caused no significant increase in porosity or other defects. Mechanical tests were carried out on tensile specimens cut from butt-welds made in 3/4 in. thick plate, with and without priming before welding. In all cases, the specimens broke in the base metal outside the area of the welded joint. Under these conditions it was not possible to detect any effect of the primer on the mechanical properties.

It is understood [4] that tests on primers have been carried out in the U.K. at the Portsmouth Dockyard and at the Naval Construction Research Establishment. The tests at the Dockyard comprised simple practical trials with various welding processes, as a result of which it was decided to amend the standing instructions to take note of the experience. Unfortunately, due to work of higher priority, it was not possible to conclude the experimental work started at the Naval Construction Research Establishment.

Wilson and Zonsveld[5] investigated the effect of a number of different types of primers on manual arc welding:

(a) Zinc dust (about 95%) with epoxy binder

(b) Two-component zinc compound on an Epikote basis

(c) Single-component welding primer, with mainly phthalate resin as binder and ferric oxide and zinc chromate as pigment

(d) Single-pack wash primers such as polyvinyl butyral phenolic resin and vinyl petroleum polyamide resin.

Fuming was less than in welding galvanized steel. The welding slag became more fluid. Generally speaking the weld quality and weld properties were acceptable.

A joint investigation[6] in Rotterdam by the Netherlands Centre for Welding Engineering and Lloyds Register of Shipping was undertaken to examine the effect on welding of epoxy primers with a high zinc content. Butt welds were made on 5/8 in. thick mild steel using manual arc, semi-automatic arc and submerged arc welding processes. No effect was noticed of the primer on the tensile and bend properties. Butt-weld tests were also made on 1-1/4 in. thick Lloyds P-5 steel plate using manually deposited rutile and low-hydrogen electrodes. The primer seemed to have little effect on the tensile, Charpy impact and bend properties, except that an inferior bend-angle was obtained on coated steel in the case of the rutile electrode, and a crack was found in the welded joint.

The Rotterdam Dockyard Co. found that porosity occurred when twin-head submerged arc fillet welds were made on primed steel[6]. It was also found that welding faults were likely to occur with single-Vee or single-bevel grooves, when welding in the horizontal-vertical position, and in the root of joints with double-bevel grooves. However root cracking did not seem to be a problem with primed steel, as it was when welding galvanized steel.

The Ship Department, Ministry of Defence, U.K. have noted[2] that porosity and loss of weld properties are unlikely to occur except in the following circumstances:

(a) When the twin-arc automatic welding process is used.

(b) When the Argon-Ox-inert gas bare wire welding process is used.

(c) Where excessive thickness of the shop primer has been applied. Attention is drawn to the recommended coating thickness, generally of the order of 0.5 to 1.0 mil.

(d) When butt welds are made at the site. Plate edges which have been prepared for butt welding shall normally not be touched up with a shop primer.

The Chemical Department of the Central Factory Inspection Service (Arbeidsinspectie) investigated the effect of zinc-bearing primers on the production of welding fumes[6]. The welding was done in an enclosed space to imitate the conditions in double bottoms and other similar spaces difficult to ventilate encountered in ship construction. It was concluded that under these conditions the total fume concentration (mainly zinc oxide and iron oxide) was excessive. Portable exhaust hoods with flexible suction pipes were recommended.

In a lecture by Dr. J. Steel[7], mention is made of the fact that the primers vary widely in composition. This wide variation is paralleled in the thermal decomposition products, some of which can be non-toxic and some dangerous. The Occupational Hygiene Services and the Institute of Welding have developed standard toxicity welding and cutting tests for primers. Tests on 15 different zinc-based primers yielded MAC figures (fume concentration) from 1 to 13. A MAC (Maximum Acceptable Concentration) figure of 5 was considered acceptable. The fume concentration depended on film thickness pigment percentage, particle size, etc.

An extensive research program on the effect of weld primers is under contract at the British Welding Research Association sponsored by a group of twelve companies[1]. Four primer types, two joint types, and three welding processes are to be investigated i.e. submerged-arc welding, bare wire CO_2 and continuous covered electrode, with and without CO_2. The funding and staffing of this program will permit much greater variety and examination in depth than the present investigation, and it is to be hoped that the findings will be made available for open publication after consideration by the sponsoring companies.

EXPERIMENTAL PROGRAM

Materials

(a) Steel

The base steel used for all the welding tests was supplied to C.S.A. specification G40.8 Grade B. The thickness was 3/4 in. The composition was as follows:

TABLE 1

Composition of G40.8B Plate Steel

	Element, Per Cent						
	C	Mn	P	S	Si	Total Al	N
Plate	0.19	1.38	0.01	0.029	0.30	0.06	0.007
Specification requirement	0.20 max	0.80/ 1.50	0.03 max	0.05 max	0.35 max	-	0.008 max

The plate was supplied in the as-rolled condition and the mechanical properties were as follows:

TABLE 2

Mechanical Properties of G40.8B Plate Steel

	Ultimate Tensile Strength, Kpsi	Yield Strength, Kpsi	Elong. in 8 in., %
Plate	73.3	45.4	25
Specification requirement	65.0/85.0	38.0 min.	20 min.

(b) Filler Materials

For metal-arc welding, alloy steel electrodes complying with C.S.A. classification E7018 were used, in 3/16 in. and 5/32 in. diameters.

Metal-inert-gas welding was done using a gas shield of argon with 2% oxygen and with filler wire of 1/16 in. diameter with the following composition:

TABLE 3

Composition of Wire for Metal-Inert-Gas Welding

	C %	Mn %	P %	S %	Si %
Analyzed	0.12	1.15	0.008	0.027	0.51
Typical (manufacturer)	0.10	1.10	0.025	0.035	0.50

(c) Primers

Two zinc-bearing primers were used in this investigation. For the purposes of this report they are identified as follows:

Product C

Product D

PRIMING

The test plates, on which welds were to be made were mechanically cleaned by sand-blasting. Any traces of oil and grease were removed with an industrial degreasing solvent.

The test primer, when used, was applied by brush to an estimated thickness of 0.010 in.

It is suggested by the manufacturer that Product C should be applied so as to yield a dry film thickness of 0.0025 in. Optimum thickness of the dry coating for Product D is stated to be 0.002-0.003 in. for smooth surfaces and 0.003-0.005 in. for rough or pitted surfaces. Since there is no satisfactory means of controlling the coating thickness, it is inevitable that greater thicknesses would occur at some locations. This might occur because of human error, equipment variations, product variations, normal overlapping in application, special attention given to seams, corners and rough spots, etc. For this reason it was decided to test the products with a coating thickness of 0.010 in. approx.

Priming was followed by curing in accordance with the manufacturer's instructions. Product C is cured by 6-48 hours air drying, the time period depending upon the temperature and the relative humidity, the curing process being accelerated by moisture. Product D is cured by 24 hours contact with a chemical curing solution, or alternatively by baking for 1 hour at 350°F with slow heating and cooling.

WELDING

Welding was carried out with normal settings, approximately at the middle of the recommended range.

TEST PROGRAM

1. Welding observations
2. Radiographic examination
3. Diffusible hydrogen in weld deposits
4. Transverse tensile tests
5. Double-fillet-weld tensile tests
6. Side bend tests
7. Impact tests on weld deposits

Experimental Work

(1) Welding

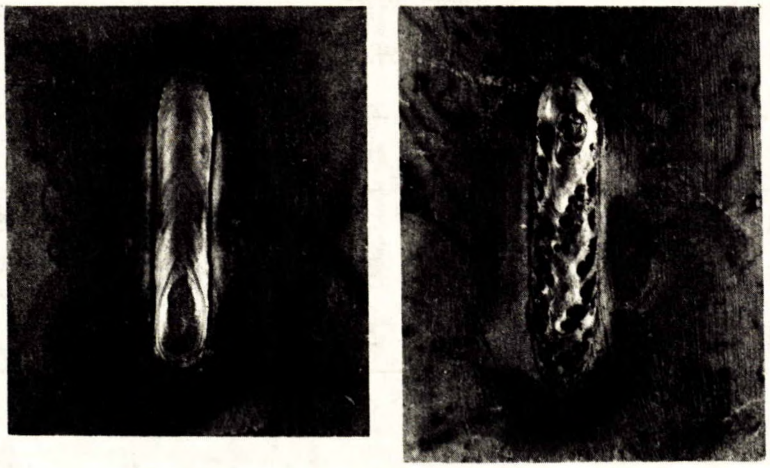
The primer coating did not appear to hinder the normal operation of the arc, and no particular difficulty was encountered in starting or maintaining the arc.

Welding was carried out in an open shop with fair ventilation. The amount of fume was greater than normally obtained with arc welding and was somewhat unpleasant.

(2) Radiographic Examination

Beads were laid down by the metal-inert-gas process on cleaned plate surfaces, with and without the primer coatings. It was intended to examine the deposits for porosity by means of radiographic examination. Ten welds were laid for each condition examined.

Very little porosity was found in any of the welds laid on uncoated plate or those laid on plate primed with Product D. On the other hand, in the case of welds laid on plate primed with Product C, the deposits were so obviously porous by visual examination that further radiographic examination was considered unnecessary. Figure 1 shows a comparison between two surface beads.



a. Uncoated   b. Primed Product C

Figure 1 - Porosity in surface beads.

(3) Diffusible Hydrogen in Weld Deposits

These tests were made under conditions previously standardized in the Physical Metallurgy Division laboratories. A weld bead is laid on the surface of a small weighed steel sample. The sample is then quenched in water, and the slag removed. Within a period of 10 seconds after the completion of welding, the cooled sample is introduced into a glycerine bath. Evolved (diffusible) hydrogen is then collected by displacement in a graduated column. The bath temperature is controlled at or slightly above room temperature. The weight of the weld deposit is subsequently obtained by difference, and the diffusible hydrogen expressed in terms of cc/100 gm weld metal. The above procedure was modified only in that some of the samples were primed before welding. The results were as shown below:

TABLE 4

Diffusible Hydrogen Test Results

	Diffusible Hydrogen (cc/100gm)
Uncoated	4.2
Product C	7.4
Product D	2.3

(4) Transverse Tensile Tests

A butt-welded sample was made, using metal arc welding, from two pieces of G40.8 Grade B steel each 12 in. x 5 in., to provide a welded sample 12 in. x 10 in. x 3/4 in. from which tensile test blanks could be cut. A double-vee preparation was used, practical for this thickness, and helpful in minimizing distortion. Two types of welding techniques were used, the first with stringer beads throughout, and the second with weave beads for the outer layers. Except as shown, the results given below represent average values after six tensile tests. The test pieces were standard A.S.T.M. round bars of 0.505 in. diameter.

TABLE 5

Transverse Tensile Test Results

	Stringer Beads			Weave Beads		
	UTS (kpsi)	Y.P.* (kpsi)	Elong. (% on 4D)	UTS (kpsi)	Y.P.* (kpsi)	Elong. (% on 4D)
Uncoated	75.3	49.6	25	72.6	45.8	29
Product C	72.2†	46.3	25	73.2	44.5	26
Product D	70.0	44.3	22	73.1†	45.4	28½

† Note: Average of three tests
* Determined as 0.2% proof stress.

(5) Double-Fillet-Weld Tensile Tests

This test, in effect a cruciform assembly destructively examined by tensile loading, is a requirement in British Standard 2549:1954 "Covered electrodes for the metal-arc welding of medium-high tensile structural steel". The test assembly, and method of tensile loading, are indicated in Figure 2. After welding, a 2-in. slice is cut for tensile testing as indicated by the broken lines in Figure 2.

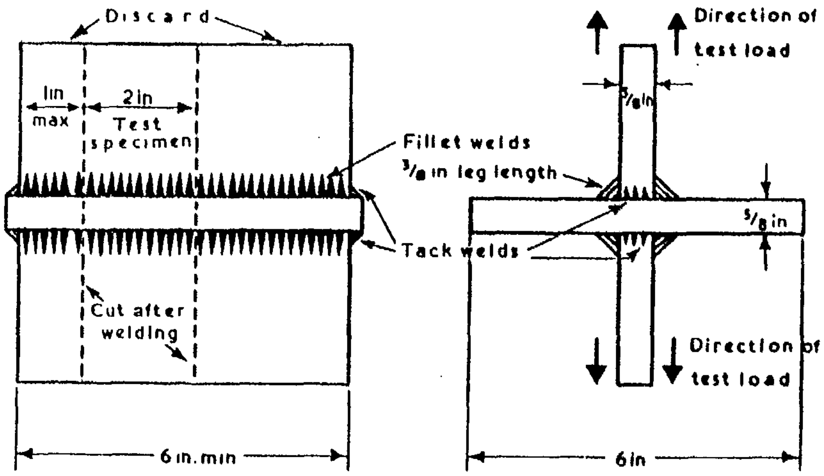


Figure 2 - Double-fillet-weld tensile test assembly.

For the purpose of the work recorded here, since only comparative results were required, it was convenient to use a plate thickness of 1/2 in. Welding was done by the metal-arc process, using a fillet leg length of 3/8 in. as prescribed in the Standard. The results shown below represent average values for four tests:

TABLE 6

Results of Double-Fillet Weld Test

	Tensile Load (lb)
Uncoated	59,500
Product C	57,400
Product D	48,600

It was noted that in the samples made using steel coated with Product D, some porosity was visible at the weld root after fracture. This may be seen in Figure 3, the porosity showing up particularly clearly on the underside of the vertical limb.

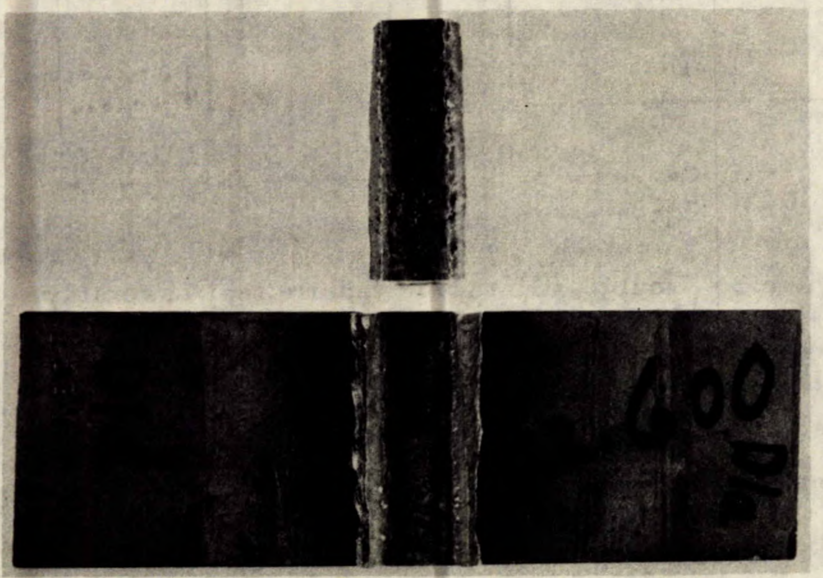


Figure 3 - Double-fillet-weld test assembly, after tensile fracture (vertical limb inverted)

(6) Side Bend Tests

The butt-welded test samples for side bend tests were made by the procedures described previously for the transverse tensile tests. Test-pieces were then cut to dimensions 10 in. x 3/4 in. x 3/8 in., and three tests were made for each condition. The tests were made with a former of

$1\frac{1}{2}$ in. diameter (i.e. radius of twice specimen thickness).

Satisfactory performance, i.e. 180° bend without cracking, was achieved in all tests.

(7) Impact Tests on Weld Deposits

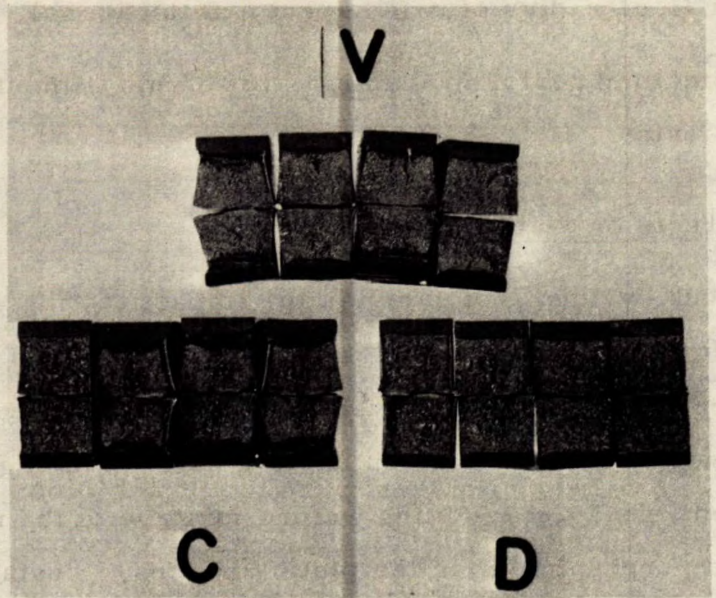
The butt-welded test samples for impact testing were made in accordance with the ASTM A233-64T specification for mild steel covered arc-welding electrodes. This involves joining two plates each 10 in. x 5 in., using a single-vee preparation in conjunction with a backing bar. Charpy-vee impact specimens were cut from the welded joint, with the notch at the centre of the weld, and perpendicular to the plate surfaces. Tests were made at 0°F and at -20°F. The results, given below, represent average values after four impact tests at -20°F and three impact tests at 0°F.

TABLE 7

Charpy-V Impact Test Results

	Impact Value (ft-lb)	
	0°F	-20°F
Uncoated	69	48
Product C	74	51
Product D	53	$14\frac{1}{2}$

The fractures of the impact samples tested at -20°F are shown in Figure 4. A higher percentage of cleavage failure may be noted in the "D" samples.



V - uncoated

C - Product C D - Product D

Figure 4 - Fractures of impact samples tested at -20°F

DISCUSSION

The presence of the primer coatings on the plate surfaces does not seem to interfere with normal welding operations or the action of the arc.

However, the claim that the primers do not adversely affect weld quality has not been substantiated by our tests. Under some conditions, Product C has caused massive porosity in the weld deposit. Product C also appears to increase the amount of hydrogen absorbed in the weld. Inferior results were obtained in the double-fillet-weld tensile test when Product D was used, apparently associated with weld root porosity. Product D also caused poor impact properties in the weld metal.

It may be noted that the values obtained for diffusible hydrogen content fall within the limit prescribed for low-hydrogen electrodes for welding mild steel: C.S.A. Standard W.48.1 permits diffusible hydrogen up to 10 cc/100 gm. However, it is usual to reduce the permitted hydrogen levels for electrodes to be used for welding higher strength steels. Thus A. W. S. Code 5.5 and associated U. S. military specifications permit for low-hydrogen electrodes, a maximum moisture content of 0.8% in 70XX electrodes 0.4% in 80XX electrodes and 0.2% in 90XX and higher strength electrodes. These values would correspond approximately to 8 cc/100 gm, 4 cc/100 gm and 2 cc/100 gm respectively. The value of 7.4 cc/100 gm obtained when Product C was used could therefore lead to cracking or other troubles depending upon the strength level of the steels being welded.

The tensile and bend properties were satisfactory. However, these tests are not particularly demanding, since any root defects in the double-vee groove would be located at the centre of the samples. It was for this reason that the double-fillet-weld tensile tests were undertaken, since root defects would assume greater significance. Under these conditions, the samples coated with Product D gave inferior results associated with weld root porosity.

The impact value for the weld metal was rather poor in the samples coated with Product D, by comparison with the other results obtained. The cause of this is unknown, but the fact may be of importance for the welding of notch-ductile steels such as G40.8 Grade B, and it should be noted that the impact value of $14\frac{1}{2}$ ft-lb at -20°F obtained in samples treated with Product D, fails to meet A. W. S. Code 5.5 requirements for low-hydrogen electrodes, i.e. 20 ft-lb average at -20°F.

Two particular products have been tested, and these differ in their effect on subsequent welding. It may be difficult to treat such products as a class. Perhaps sufficient work has been done, taken in conjunction with previous investigations, to suggest some restrictions on their use.

These products may be used for mild steel in ordinary structural service, except under the conditions outlined below.

These products are not recommended for use under the following conditions, unless care is taken to remove the coatings from the weld area:

(a) Where twin-submerged arc or other double fillet processes are to be used.

(b) Where single-vee grooves are used.

(c) Where brittle failure is a dominant factor in design.

(d) When alloy steels or higher-strength steels are used.

(e) Where inspection is inadequate to ensure that pre-cleaning and degreasing of the steel, mixing of the primers, application, and curing are properly carried out.

(f) When welding is to be done in enclosed spaces without good ventilation.

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