

1

3,667,924

STRESS RELIEVED WELDED STEEL COMPOSITE
William T. De Long and Paul T. Corcoran, West Manchester Township, York County, Pa., assignors to Teledyne Inc., Los Angeles, Calif.

No Drawing. Filed Dec. 30, 1969, Ser. No. 889,320

Int. Cl. B23b 15/00; B23p 3/00

U.S. Cl. 29—196.1

1 Claim

ABSTRACT OF THE DISCLOSURE

A low alloy high strength steel weld deposit of high toughness and superior resistance to thermal degradation and which, after a stress relief consisting of a 16-hour soak at 1025° F. followed by cooling at a rate of 200° F. per hour, has Charpy V-notch impact strength of at least 20 ft.-lbs. at -60° F. at yield strength levels which are selectable between about 90K s.i. and about 145K s.i., the deposit consisting essentially of

Element	Percent by Weight	
	Broad	Preferred
Carbon.....	1.12	1.10
Manganese.....	.25-.9	.35-.75
Silicon.....	.20-.70	.25-.55
Chromium.....	2-2.0	2-1.55
Nickel.....	2.0-4.5	3.0-4.0
Molybdenum.....	2-1.2	.35-1.0
Phosphorus.....	1.020	1.012
Sulfur.....	1.020	1.012
Iron.....	Balance	Balance

¹ Maximum.

also a low alloy steel weld deposit having a yield strength of at least 130K s.i. and Charpy V-notch energy absorption at -60° F. of at least 20 ft.-lbs. after being stress relieved by soaking for 16 hours at 1025° F. followed by cooling at a rate of 200° F. per hour, the deposit consisting essentially of

Element	Percent by Weight		Specific example
	Broad	Preferred	
Carbon.....	.05-.12	.07-.10	.08
Manganese.....	.25-.9	.35-.75	.5
Silicon.....	.20-.70	.25-.55	.4
Chromium.....	6-2.0	.75-1.35	1.0
Nickel.....	2.0-4.5	3.0-4.0	3.5
Molybdenum.....	.3-1.2	.5-1.0	.75
Phosphorus.....	1.020	1.012	<.01
Sulfur.....	1.020	1.012	<.01
Iron.....	Balance	Balance	Balance

¹ Maximum.

The invention herein described was made in the course of or under a contract or subcontract thereunder with the Department of the Navy.

This invention relates to steel weld deposits; more particularly it relates to low alloy high strength steel weld deposits characterized by improved toughness and superior resistance to thermal degradation during stress relief.

In the field of low alloy high strength steels with yield strengths above 90K s.i., particularly HY-130/150 type steels (covered by Military Specification MIL-S-24371 (SHIPS), dated Dec. 19, 1968) with yield strengths of at least 13K s.i., there has been a need for high performance weld metals which in a single deposit will have yield and tensile strengths and impact toughness approximately

2

equal to those of the base metal in both the as-deposited and the stress-relieved conditions. Weld deposited metal is always under a handicap compared with plate material and must be more shrewdly formulated because it lacks the advantages of the mechanical hot work treatments which produce grain refinement in plate material. In spite of this handicap low alloy steel weld deposit analyses and methods of deposition have been developed which produce as-deposited metal with yield strength at least matching that of the available hot worked and heat treated plate material, coupled with suitable toughness. Requiring the highest quality welding processes, such deposits were recently produced by means of inert gas shielded methods used with high purity alloy-bearing filler wires. This level of performance has first been achieved with deposits from manual low hydrogen lime-fluoride covered electrodes, which was a more difficult goal. However, all such weld metals, by whatever process they have been produced, have heretofore been susceptible to temper embrittlement produced during thermal stress relief treatments, which lowered their impact strength below the desired level of 20 ft.-lbs. at -60° F.

We are able to produce weld deposits which when applied according to recommended principles known to the art and described hereinafter exhibit yield strengths selectable between 90K s.i. and about 145K s.i. and Charpy V-notch impact energy absorption of over 20 ft.-lbs. at -60° F. both in the as-deposited condition and after a standard stress relief treatment consisting of a 16-hour soak at 1025° F. followed by cooling at a rate of 200° F. per hour. Other mechanical properties of our new weld deposits, such as percent elongation, tensile strength, reduction of area, hardness and yield strength-to-tensile strength ratio remain satisfactory after such stress relief.

Our new weld deposits were developed in connection with a study of the HY-130/150 area, which currently requires a 130K s.i. minimum yield strength, although they have been found broadly to have yield strengths which are selectable between about 90K s.i. and about 145K s.i. As compared to earlier weld metals of the HY-130/150 type, which are suitable for as-welded use but not for stress relieved use, our weld deposits are characterized by a novel balance of those chemical elements which have proven most effective in the as-welded grades, and also by a retention of the earlier emphasis on limitations in the harmful elements phosphorus and sulfur to levels below .020 percent by weight and preferably below .012 percent by weight.

A particularly attractive aspect of our weld deposits is that they may exhibit desirable stress-relieved properties when deposited with low hydrogen lime-fluoride covered electrodes utilizing conventional commercial quality rimmed steel core wires. Such electrodes, which were the chosen means for producing weld deposits which established the existence and limitations of our invention, offer significant economic advantages over the simpler but much more expensive high purity wire and gas-metal-arc (GMA) processes which are also applicable and which have heretofore been widely used in investigating and producing HY-130/150 weld metals.

Accordingly, we provide a low alloy high strength steel weld deposit of high toughness and superior resistance to thermal degradation and which, after a stress relief consisting of a 16-hour soak at 1025° F. followed by cooling at a rate of 200° F. per hour, has Charpy V-notch impact strength of at least 20 ft.-lbs. at -60° F. at yield strength

3

levels which are selectable between about 90K s.i. and about 145K s.i., the deposit consisting essentially of

	Percent by weight	
Carbon -----	max--	.12
Manganese -----		.25-.9
Silicon -----		.20-.70
Chromium -----		.2-2.0
Nickel -----		2.0-4.5
Molybdenum -----		.2-1.2
Phosphorus -----	max--	.020
Sulfur -----	max--	.020
Iron -----	Balance	

In a preferred form the deposit consists essentially of

	Percent by weight	
Carbon -----	max--	.10
Manganese -----		.35-.75
Silicon -----		.25-.55
Chromium -----		.2-1.35
Nickel -----		3.0-4.0
Molybdenum -----		.35-1.0
Phosphorus -----	max--	.012
Sulfur -----	max--	.012
Iron -----	Balance	

In embodiments especially suited for use in welding HY-130/150 base material we provide a low alloy steel weld deposit having a yield strength of at least 130K s.i. and Charpy V-notch energy absorption at -60° F. of at least 20 ft.-lbs. after being stress relieved by soaking for 16 hours at 1025° F. followed by cooling at a rate of 200° F. per hour, the deposit consisting essentially of

	Percent by weight		
Element	Broad	Preferred	Specific example
Carbon-----	.05-.12	.07-.10	.08
Manganese-----	.25-.9	.35-.75	.5
Silicon-----	.20-.70	.25-.55	.4
Chromium-----	.8-2.0	.75-1.35	1.0
Nickel-----	2.0-4.5	3.0-4.0	3.5
Molybdenum-----	.3-1.2	.5-1.0	.75
Phosphorus-----	1.020	1.012	<.01
Sulfur-----	1.020	1.012	<.01
Iron-----	Balance	Balance	Balance

¹ Maximum.

Realization of the optimum properties of our new weld deposits will depend on the conditions under which they are deposited, as will be appreciated by those skilled in the art. In the HY-130/150 area certain practices, such as low welding heat input and small bead size, are known to maximize as-welded strength and toughness of the deposit. In addition to such general practices the specific welding process employed to produce our new weld deposits will have a definite effect on the degree of retention of the maximum deposit properties attainable; it is well established that the higher the weld metal purity, the more its properties will approach the optimum for its overall alloy balance. "Purity" in this context not only means low levels of residual or tramp elements such as phosphorus, sulfur, nitrogen and oxygen but also includes aspects such as size and shape of inclusions, etc. The gas-tungsten-arc (GTA) process with pre-alloyed high purity filler metal additions, which provides the highest purity weld metal, can be expected to be optimum for producing our deposits; somewhat lower on the scale, although still very good, is the GMA process utilizing argon-oxygen or equivalent shielding gases and pre-alloyed electrode wire. As above indicated, we have also found that our new analysis can be weld deposited with good results close to those obtained with the GMA process and at much lower cost with properly formulated high quality low hydrogen lime-fluoride covered electrodes. Deposits produced by other types of covered electrodes or submerged arc welding can be expected to exhibit inferior properties to a degree dependent on the specific process used and the purity of the resultant weld metal.

4

The low hydrogen lime-fluoride covered electrode which we have used for producing our deposits meets a general specification for this class of electrode, and consists of a mild steel core and a lime-fluoride coating thereon, the electrode containing by weight about 45 percent to about 80 percent core and about 20 percent to about 55 percent coating, the coating containing by weight of the electrode up to about 30 percent iron powder and alloying metal powder, about 2 percent to about 7 percent deoxidizer metal powder, about 4 percent to about 15 percent metal fluoride, about 5 percent to about 15 percent alkaline earth carbonate, 0 to about 10 percent slag builder and modifier and about .5 percent to about 8 percent inorganic binder material. Although we have chosen to supply all alloy by way of the coating for reasons of economy in our electrode, it is of course possible to introduce all or part of the alloy through the core wire.

Other details, objects and advantages of the invention will become apparent as the following description of certain present preferred embodiments thereof proceeds.

TABLE 1

Welding procedures—HY-130/150 test series

Plate material: 2 pieces of one inch thick U.S. Steel HY-130(T) plate minimum dimensions 10" long x 4" wide.

Chemistry—0.12% C, 0.90% Mn, 0.34% Si, 0.59% Cr, 4.96% Ni, 0.50% Mo, 0.002% P, 0.008% S, 0.06% Cu, 0.064% V, 0.025% Al.

Joint: Type—single V

Preparation—Flame cutting followed by grinding

Bevel—22½° on plate

Electrode: Diameter—5/32"

Coating—Low hydrogen lime-fluoride type.

Core wire: Type—conventional commercial-quality rimmed steel

Chemistry—0.07% C, 0.50% Mn, 0.005% Si, 0.007% P, 0.020% S.

Backup plate: U.S. Steel HY-130(T) one-inch-thick plate, one inch minimum in width x joint length

Welding position: Flat

Welding current: 185±5 amps DC, reverse polarity

Welding voltage: 24 volts

Heat input: 30±2 kilojoules per inch

Preheat and interpass temperature: 250° F.±25° F.

Interpass delay: 1 hour minimum.

Table 1 lists constant parameters maintained throughout a test series run with 5/32" diameter low hydrogen lime-fluoride covered electrodes to compare the performance of our weld deposits with other weld deposits of essentially the same as-welded strength. This series was designed primarily to explore the general HY-130/150 area. In order to minimize the effects of welding process variables on the performance of the deposits, a major effort was made to keep the welding of all test plates identical within the limitations inherent in shielded metal arc welding. Only one welder and one power source were used throughout the series. All test weldments were made in the flat position using reverse polarity direct current. Multipass welds were preparing using stringer beads and a temper bead deposition sequence. Welding parameters were controlled so that a calculated heat input of 30±2 kilojoules per inch would be maintained. Each pass in the test weldment was completed with one electrode only and no starts or stops were located in the test area. Preheat and interpass temperatures of the test weldment were maintained at 250±25° F. In an attempt to preclude any hydrogen-caused cracks in the deposit a one hour minimum interpass delay time was used. All weld-metal tensile bolts (.357" diameter) and Charpy V-notch impact specimens were machined from the deposits and tested both in the as-welded condition and after a 16-hour soak at 1025° F. followed by cooling at a rate of 200° F. per hour.

TABLE 2

[Weld deposit chemical analysis]

Deposit	C	Mn	Si	Cr	Ni	Mo	P	S
A.....	.077	1.07	.41	1.09	3.52	.35	.003	.004
B.....	.086	.76	.44	.78	5.14	.13	.002	.004
C.....	.122	.55	.47	.53	6.26	.35	.002	.004
D.....	.076	1.09	.38	.50	3.56	.74	.003	.005
E.....	.084	.84	.46	.73	5.10	.65	.004	.003
F ¹	.083	.56	.36	.98	3.62	.75	.004	.002
G.....	.126	1.07	.41	.52	3.60	.39	N/D	N/D
H.....	.133	.59	.53	.54	3.65	.75	N/D	N/D
I.....	.086	.77	.47	.80	5.14	.67	N/D	N/D
J ¹	.124	.53	.45	.96	3.68	.36	N/D	N/D
K.....	.084	.79	.45	1.25	5.08	.68	N/D	N/D
L.....	.082	.82	.42	.76	5.17	.65	N/D	N/D
M ¹	.088	.66	.53	.52	3.53	.39	N/D	N/D
N.....	.101	1.16	.40	2.60	.25	.90	N/D	N/D
O.....	.079	.73	.37	1.51	1.90	.73	N/D	N/D
P ¹	.084	.83	.43	.76	2.22	.65	N/D	N/D
Q.....	.082	.48	.32	.98	1.97	1.23	N/D	N/D
R ¹	.082	.48	.27	.96	3.50	.78	N/D	N/D

¹ Examples of applicants' improved weld deposits.² N/D: Not determined—estimated at less than .010 percent; in same range as Deposits A through F.

With the above described constant preparation and testing conditions, the weld deposits had the chemical analyses listed in Table 2. The experiments employed were selected to fall into compositional arrays or patterns which were most favorable to graphical and statistical studies of the physical effect conferred by each alloying element.

TABLE 3

[As-welded weld deposit mechanical properties]

Deposit Number	Yield strength (0.2% offset) K s.i.	Tensile strength, K s.i.	Yield/tensile ratio	Elongation in 1.4 in., percent	Reduction of area, percent	Charpy V-notch energy absorption, ft.-lb.		
						+80° F.	-0° F.	-60° F.
A.....	135	152.5	.89	11.4	56.3	78	69.5	55
B.....	134	156.5	.86	15.7	54.8	62.5	52	41
C.....	133	167	.80	15.7	46.1	54.5	47	34
D.....	143	149.5	.96	19.3	64.1	84.5	72.5	70.5
E.....	136	161.5	.84	12.2	54.8	53	42.5	24.5
F ¹	137	158	.87	18.6	62.1	82	71	57
G.....	140	160	.88	17.2	56.3	67	53	46
H.....	144	166	.87	20.0	58.5	61	46.5	35
I.....	134	163	.82	16.4	57.7	56.5	36.5	17.5
J ¹	134	159.5	.84	16.4	57.1	62	52	40
K.....	130	164	.79	17.9	51.0	47.5	31.5	18
L.....	136	158.5	.86	14.3	39.3	62.5	47.5	34.5
M ¹	117	130.5	.90	17.2	62.5	113	104	88.5
N.....	150	163	.92	15.7	58.5	42	21.8	10.3
O.....			Not tested in as-welded condition					
P ¹	123	140.5	.88	19.3	66.7	107.5	78	39
Q.....			Not tested in as-welded condition					
R ¹			Not tested in as-welded condition					

¹ Examples of applicants' improved weld deposits.

TABLE 4

[Stress-relieved ¹ weld deposit mechanical properties]

Deposit Number	Yield strength (0.2% offset) K s.i.	Tensile strength, K s.i.	Yield/tensile ratio	Elongation in 1.4 in., percent	Reduction of area, percent	Charpy V-notch energy absorption, ft.-lb.		
						+80° F.	-0° F.	-60° F.
A.....	132	139	.95	17.9	60.7	35	18.5	13.5
B.....	136	141	.96	17.2	55.5	24	12.5	10.5
C.....	146	159.5	.92	19.3	55.5	28.5	18.5	9.5
D.....	146	153.5	.95	19.3	59.9	10	8.5	4
E.....	141	152	.93	17.2	47.0	11	9	8
F ¹	142	153	.93	18.6	60.7	69.5	46.5	27.5
G.....	142	150.5	.94	18.6	54.8	32.5	18.5	13
H.....	158	168	.94	16.4	45.4	20.5	12	6.5
I.....	145	158.5	.91	19.3	55.5	7	5.5	3.5
J ¹	137.5	148.5	.93	14.3	56.3	51.5	32	20.5
K.....	136.5	151	.90	17.2	61.3	11	10	8.5
L.....	142	153	.93	16.4	59.9	13	8	5.5
M ²	123	132.5	.93	20.0	61.3	115.5	106.5	65
N.....	140	154	.91	20.0	59.9	43.5	24	14.5
O.....	130	142	.92	21.5	62.7	68	41	15
P ²	128	141	.91	20.0	64.1	96.5	87.5	46
Q.....	136	149	.91	18.6	59.9	43.5	18.5	12
R ¹	134	146	.92	20.0	58.5	65.5	46.5	22

¹ 16-hour soak at 1,025° F., followed by cooling at 200° F. per hour.² Examples of applicants' improved weld deposits.

Results of mechanical tests in the as-welded condition are listed in Table 3 and those of tests in the stress-relieved condition are listed in Table 4.

As indicated in the tables, weld deposits F, J, M, P and R are examples of our improved weld deposits. While the other deposits shown are outside the compositional limits of our improved weld deposits in respect to one or more

elements, their compositions were selected to reveal alloy effects with the minimum number of tests. Deposits F, J and R meet the requirements for HY-130/150 type weld metals, showing yield strengths greater than 130K s.i. both as-welded and after stress relief; deposits M and P are somewhat lower than 130K s.i. in yield strength but still show excellent overall properties both as-welded and after stress relief.

Graphical and statistical study of the data generated in this and other series produced the above described limits on analyses of deposits of the invention.

We are unable to state with certainty why the alloy balance of our improved weld deposits is superior to that of similar known low alloy high strength weld deposits in the retention of properties on stress relief, particularly toughness at -60° F.; however, it appears that the chief factor is low manganese, combined with increased chromium where necessary to maintain the strength level. For example, deposit D in Tables 2, 3 and 4 is a typical known deposit with very good as-welded properties (Table 3); stress relief of this deposit causes severe embrittlement, as indicated by the drastic deterioration in Charpy V-notch toughness at all three testing temperatures (Table 4). Deposit D contains 1.09 percent manganese and .50 percent chromium; deposit F, a preferred embodiment of our improved weld deposits for use in

the HY-130/150 area, is virtually identical to deposit D except that it contains .56 percent manganese and .98 percent chromium, just the reverse of the quantities of those elements in deposit D. The lower limit of .25 percent on manganese is effective in avoiding possible problems due to insufficient tying up of sulfur with manganese below this level. While nickel has always been a principal

7

alloy element relied upon to improve low temperature impact strength, our investigation shows that nickel has a somewhat unclear effect; our evidence indicates that levels of about 2 percent and about 3.5 percent are both favorable to good stress-relieved toughness, with 3.5 percent nickel being optimum, but we have found that high nickel, on the order of 5 percent or higher, is definitely harmful to stress-relieved impact properties. The low sulfur and phosphorus levels of our deposits, while not of themselves conferring high strength or good impact qualities, certainly aid in maintaining good properties; all six deposits for which phosphorus and sulfur were determined in the series of Tables 2 through 4 showed very low phosphorus and sulfur levels but only deposit F exhibited the desired stress-relieved mechanical properties. Limits on other elements in our deposits define what we believe to be the best area for securing the desired strength levels.

As above indicated, realization of maximum properties in our deposits is dependent on the use of favorable welding practices and parameters. With unfavorable practices, such as high heat input, no interpass delay, etc., both the stress-relieved and the as-welded properties can be impaired; however, even in such cases the stress-relieved properties, particularly toughness, of our improved weld deposits can be expected to be superior to those of similar known deposits subjected to the same practices.

While we have described certain present preferred embodiments of the invention it is to be distinctly understood that the invention is not limited thereto but may be otherwise variously embodied within the scope of the following claims.

We claim:

1. A stress relieved composite which has been subjected to soaking for 16 hours at 1025° F. followed by cooling

8

at a rate of 200° F. per hour comprising a base consisting essentially of

	Percent by weight
Carbon -----	max. .14
Manganese -----	.55-.95
Silicon -----	.18-.37
Chromium -----	.36-.74
Nickel -----	4.68-5.32
Molybdenum -----	.27-.68
Vanadium -----	.04-.11
Iron -----	Balance

having thereon a weld deposit consisting essentially of

	Percent by weight
Carbon -----	.05-.12
Manganese -----	.25-.9
Silicon -----	.20-.70
Chromium -----	.6-2.0
Nickel -----	2.0-4.5
Molybdenum -----	.3-1.2
Phosphorus -----	max. .020
Sulfur -----	max. .020
Iron -----	Balance

References Cited

UNITED STATES PATENTS

2,327,490	8/1943	Bagasar -----	75-128 W
2,624,687	1/1953	McMullan -----	75-128 W
3,175,902	3/1965	Ferree -----	75-128 W
3,254,991	6/1966	Shimmin -----	75-128 W
3,290,128	12/1966	Manganello -----	75-128 T

HYLAND BIZOT, Primary Examiner

U.S. Cl. X.R.

148-34

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,667,924 Dated June 6, 1972

Inventor(s) William T. DeLong and Paul T. Corcoran

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

At each of the following listed places in the specification, correct "K s.i." to read --ksi--:

Column 1, line 19 (2 occurrences)

" 1, " 33

" 1, " 61

" 1, " 64

" 2, " 26 (2 occurrences)

" 2, " 37

" 2, " 39

" 2, " 40

" 3, " 1

" 3, " 2

" 3, " 29

" 5, table 3, in the second and third column headings

" 5, " 4, in the second and third column headings

" 6, line 4

" 6, " 6

Column 4, line 61, change "preparing" to --prepare--.

Column 5, in each of tables 2, 3 and 4, delete the brackets before and after the table heading.

Signed and sealed this 26th day of September 1972.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents