ELECTROSLAG STRIP OVERLAY OF PIPE, FITTINGS, AND PRESSURE VESSELS

By Capitanescu, Dan
President and Welding Specialist
CAPITAN OVERLAY TECHNOLOGIES INC.
9304 Horton Road SW, Calgary, Alberta, Canada T2V 2X4, capitand@capitanoverlay.com

ABSTRACT

ElectroSlag Strip Overlaying (ESSO) process has been around since 1970. ESSO process had limited acceptance due to a few problems associated with the use of this process in its very early stage. Limited knowledge and, most significantly, poor quality of the equipment and welding flux gave the ESSO process a bad name. However, this process is well accepted today and used in North America, Europe and Japan.

The ESSO process provides low dilution overlays at high deposition rates, excellent and consistent deposit chemistry with excellent surface quality, and virtually no defects. Capitan has taken this process one step further through extensive research and development of the process itself as well as the equipment. The improvement brought to the process warranted the issuance in May 2000 of an US patent.

This study demonstrates the feasibility of this process with immediate positive production results. The main achievements of this work are as follows:

- Development of six various strip-flux combinations on three different base materials: carbon steel, 1 ¼ Cr/.5 Mo and 2 ¼ Cr/1 Mo, fully tested with: penetrant, ultrasound, bends, hardness, overlay chemistry, corrosion and hydrogen disbonding.
- 12" dia. 90° hot formed elbows from straight pipe electroslag overlayed with "1 layer" and "2 layer" Alloy 625
- a very unique development of miniaturized overlaying equipment able to perform overlay in pipe with diameters as low as 10" (254 mm). This development has large applications in the field of offshore, petrochemical, refining, pulp and paper and power generation industries. The aftermath of this development was its immediate acceptance by major end users with the completion of four projects of overlayed pipe in the USA and Far East Asia.

KEYWORDS

ESSO – ElectroSlag Strip Overlay
SAWSO – Submerged Arc Weld Strip Overlay
SAWO – Submerged Arc Weld Overlay
TDR – True Deposition Rate
Trailing Flux for ESSO

1. Introduction

The ElectroSlag Strip Overlaying process (ESSO) has been experimented with since 1970/1971. Taking into account the above statement, ESSO is a relatively newer process compared with the well known and seemingly similar process, Submerged Arc Welding Strip Overlaying process (SAWSO).

ESSO has gained widespread acceptance since its initial experimental years. The growth of applications for ESSO has been somewhat limited by one or two isolated cases, in its early years, of poor quality overlays for use in demanding environments of high temperatures/pressures and in the presence of hydrogen. Some disbonding of the overlay took place and blame was directed at the process itself rather than at the poor knowledge, equipment, materials or technique of the operator. However, the process is widely accepted today and utilized in North America, Europe, and Japan.

There are well known technical and economical advantages of the ESSO process including:

- low dilution levels;
- very good and consistent quality of overlay deposits;
- significantly higher deposition rates than SAWSO;
- excellent surface quality.

This report examines the following:

- a study of six different strip-flux combinations (316L, 317L, Alloy 625, Alloy 400, Alloy 600, 347 Strip types, and EST 122, EST122Mo, EST201 flux types) performed on three different base materials: Carbon Steel HIC plate, 1 ¼ Cr/.5 Mo and 2 ¼ Cr/1 Mo, fully tested with penetrant, ultrasonic, bends, hardness, overlay chemistry, corrosion (ASTM G48 and 262), ferricyanide (Alloy 400) and hydrogen disbonding;

- a full assessment, including all pertinent tests, of 90° elbows hot formed from pipe overlayed with Alloy 625 (ERNiCrMo-3) by the ESSO process;
- and finally a very unique development of miniaturized overlaying equipment able to perform ESSO in pipe with diameters as low as 10 inches (254 mm).

2. Technical Characteristics of ElectroSlag Strip Overlay

The basic difference between ESSO and SAWSO is found in the mode of the melting process of the overlaying consumable (strip).

During the SAWSO process, a permanent electric arc is established between the strip and the base material being overlayed. In other words, the arc "bites" continuously from the base material creating a mixed molten pool of base material and strip.

On the other hand, the ESSO process is significantly different due to the fact that the required heat to melt the strip is obtained by the welding current flowing through a shallow molten pool of electrically conductive slag. [1]

Both processes use flux. The SAWSO process has the flux fed in front and behind the strip; it is an arc process (Fig. 1). The ESSO process has the flux fed only in front of the strip; it is an arcless process (Fig. 2).

Due to its characteristics, the ElectroSlag Strip Overlay process maintains all the advantages typical for SAWSO (high productivity, smooth surface, "near zero" repair rate, etc.) and yields overlay deposits with half or less dilution compared to SAWSO process.

3. Welding Conditions (Strip Electrodes, Fluxes, Welding Deposition Rates)

3.1 Strip Electrodes

The most popular sizes for strip electrodes are 2 3/8" x 3/64" (60 mm x .5 mm) and 1 3/16" x 3/64" (30 mm x .5 mm). Strips with sizes 2 3/8" (60 mm) or more are used on large diameter vessels with thick walls. Strip electrodes are available in a large variety of chemical compositions. This study being reported is done with some of the most popular choices of strip: 316L, 317L, 347, Alloy 400, Alloy 600 and Alloy 625.

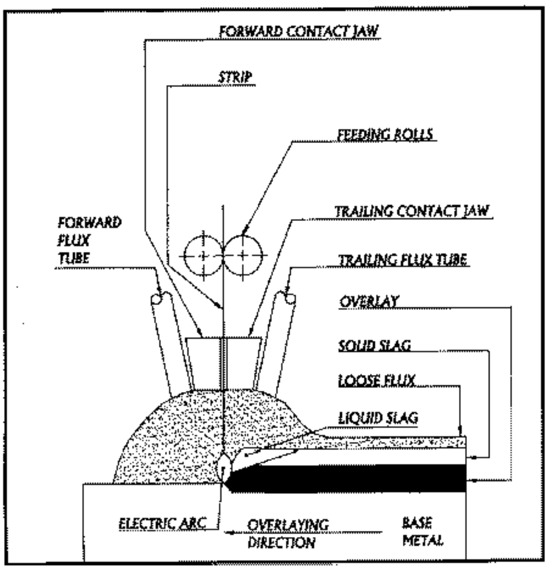

Fig. 1

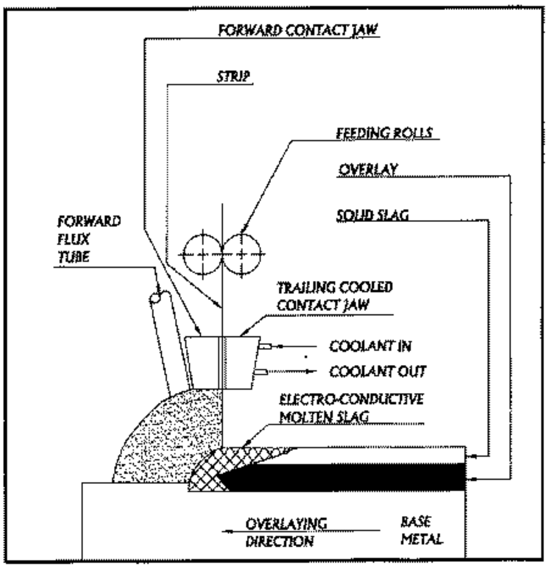

Fig. 2

3.2 Fluxes

As previously mentioned, the main difference between SAWSO and ESSO is in the flux. The fluxes used for ElectroSlag Strip Overlay are totally different from those used for submerged arc overlay. The electroslag overlay fluxes contain a large amount of CaF_2 (Calcium Fluoride) in order to allow high electro conductivity of the molten pool. At the same time, ESSO fluxes must be free of gas yielding components such as $CaCO_3$ (Calcium Carbonate) which would allow gases to form and prevent good contact between the strip electrode and the molten slag.

This study presents three different electroslag fluxes in combination with six types of strip electrodes. Recently new fluxes were developed to allow significantly increased welding speeds. Due to developing costs and higher dilution rates obtained with high speed fluxes they are still in the development stage.

3.3 Welding Parameters

The ElectroSlag Strip Overlay process is a much more "weld parameter" (current, voltages, welding speed and stick out) dependent system than the regular SAWSO process. Using the SAWSO process, variations of ± 10% of the welding parameters do not mean much as far as the final quality of the overlay deposit is concerned.

For the ESSO process, 26 versus 28 volt, 8 versus 9 IPM (203 versus 220 mm/min) or 1" (25.4 mm) versus 1 3/8" (35 mm) electrode stick-out would mean the difference between excellent overlay deposits versus unacceptable overlay deposits.

The direct effect of the welding current on the weld bead thickness, penetration, dilution and shape, already has been presented in previous works.[2] It is important to understand that for a certain base material thickness and a given strip/flux combination, only one set of welding parameters with a narrow margin for variation is going to yield a proper bead thickness, shape, penetration, ties-in and dilution.

For the present study, the ideal welding parameters to achieve the best results for the given strip/flux combinations are presented in Table 1.

TABLE 1

WELDING PARAMETERS								
STRIP TYPE 30 X .5 mm (1 3/16" x 3/64")	**FLUX TYPE**	**CURRENT (AMPS)**	**VOLTAGE (VOLTS)**	**WELDING SPEED IPM (mm/min)**	**STRIP ELECTRODES STICK-OUT INCHES (mm)**	**FLUX BURDEN INCHES (mm)**		**WELD DEPOSIT APPEARANCE**
						FRONT	**BACK**	
ER316L (21.13.3L)	EST 122	500 – 525	27 – 28	8 (203)				VerySmooth
ER317L (21.13.3L)	EST 122Mo	500 – 525	27 - 28	8 (203)				VerySmooth
ER347 (21.11.LNB)	EST 122	500 – 525	27 – 28	8 (203)	1 ¼" (32)	1" (25.4)	¼" (6.4)	Smooth
ERNiCr-3 (ALLOY 600)	EST 201	400 – 450	26 – 27	7.5 (190)				Smooth
ERNiCrMo-3 (ALLOY 625)	EST 201	525 – 550	27 – 28	8 (203)				Smooth
ERNiCu-7 (ALLOY 400)	EST 201	450 - 500	26 – 28	7.5 (190)				Acceptable

3.4 Deposition Rates

In direct comparison with the Submerged Arc Welding Overlay (SAWO) process using 1/16" (1.6 mm) diameter filler metal, the ElectroSlag Strip Overlay process is about 300% more productive with about 50% reduction in dilution.

A pass of approximately 1 ¼" (32 mm) width and 12" (305 mm) length performed with ESSO process will yield approximately .75 lb. (340 g) of overlay deposited in 1.5 minutes which translates into a deposition rate of 30 lb. (13.6 kg) per hour. An identical surface of 1 ¼" (32 mm) width x 12" (305 mm) length to be overlayed with SAWO process using 1/16" (1.6 mm) filler will yield the same amount of overlay deposit. However, it is performed in four passes totaling 4.4 minutes which translates into a deposition rate of 10.2 lbs. (4.6 kg) per hour (Fig. 3). The ESSO process has a 50% drop in dilution rate, increased overlay surface quality, and significantly cuts down the time required to remove the slag. Also, there is very significant improvement in overlay deposit chemistry of "1 layer" ESSO versus "1 layer" SAWO with 1/16" (1.6 mm) diameter filler metal. [7]

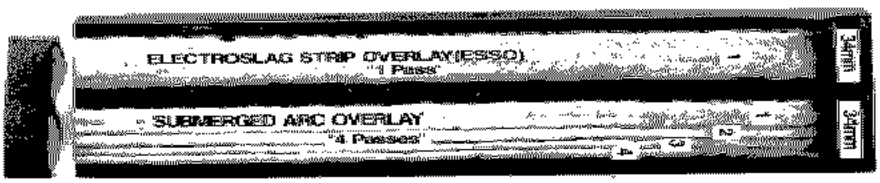

Fig. 3

The ElectroSlag Strip Overlay process is an excellent candidate for high deposition/low dilution rates of overlays in any given case. However, due to the clean-up time between passes, the true deposition rate (TDR) would be 20 lbs. (9 kg) per hour for ESSO process and 5 lbs. (2.26 kg) per hour with SAWO process.

4. **ElectroSlag Strip Overlay Equipment for Small Pipe (10" Diameter) Interiors**

Regular submerged arc electroslag equipment was developed for the purpose of overlaying large diameter vessels, forging, etc. However, the regular "off the shelf" strip overlaying equipment is bulky and by no means appropriate for overlaying pipe or fittings with interiors less than 30 – 36 inches (762 – 914 mm).

This report introduces the unique development of reliable ElectroSlag Strip Overlay (ESSO) equipment capable of overlaying pipe and fittings with diameters as low as 10 inches (254 mm) and uninterrupted lengths of pipe as long as 10 - 15 feet (3 – 4.5 m) as shown in Fig. 4.

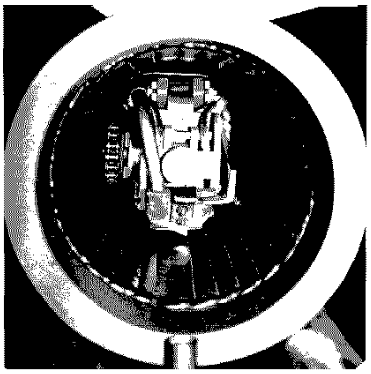

Fig. 4

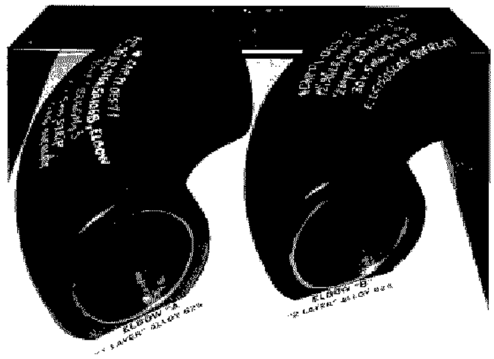

Fig. 5

A 12 inch (305 mm) diameter pipe was overlayed using the ESSO process with "1 layer" and "2 layer" ERNiCrMo-3 deposits and then hot formed into 90° LR elbows as shown in Fig. 5. Extensive testing was performed on these two elbows with results discussed in Section 6 of this report. The challenge of developing such equipment is to bring all the elements required for a normal, large size ElectroSlag Strip Overlaying head into a very small and confined space as low as 10" (254 mm) in diameter.

The most important facts to consider are:

- the strip has to be curved 90° with a radius of 1" or smaller and still, fed continuously towards the base material;
- the flux has to be delivered to the contact nozzle without any interruptions or volume variations about 10 – 15 feet (3 – 4.5 m) away from the flux source;
- the contact nozzles (the trailing jaw) has to be water cooled;
- the head has to be heat protected due to the very small and confined space the overlaying process takes place in.

Besides the very unique development of the ElectroSlag Strip Overlaying head, another important development has been achieved. Due to the particulars of the ElectroSlag Strip Overlaying process with a heavy layer of molten slag trailing the ESSO head, flux is fed only ahead of the strip (Fig. 2). Normally no flux is being fed behind it, leaving the trailing jaw exposed to the molten slag causing a number of inconveniences:

- it is too bright for the operator to look towards the head while overlaying takes place without wearing eye protection (goggles, welding helmet, etc.);
- the trailing contact jaw is directly exposed to the very hot molten pool and, should the cooling system be interrupted for any reason, the copper jaw will be melted or distorted and the overlaying process interrupted which would be a very big inconvenience if the interruption takes place, for example, in the middle of a 10" (254 mm) diameter pipe, 15 ft. (4.5 m) length;
- significant spattering takes place with drops of molten metal spread on the nozzles, flux guides, adjacent overlay, etc.

When flux is being fed only behind the strip, very shallow marks are shown on the overlay surface. These marks are produced by the entrapped gases in the solidifying slag not being able to escape through the molten sag with the heavy burden of flux on top of it.

Through extensive trials a compromise solution was found. A certain amount of flux (called here "trailing flux") is also fed behind the strip with the following results:

- molten slag is not fully exposed to the naked eye making it easy to follow and appealing to the operator;
- no spattering takes place;

- strip feeding is smooth and continuous due to proper cooling of the trailing jaw and not being directly exposed to the heat of the molten slag;
- and last but not least, the overlay deposit shows no marks due to the trapped gases in the slag.

5. Hydrogen Disbonding in ElectroSlag Overlayed Products

Hydrogen disbonding is a problem mainly associated with large pressure vessels used in processes of hydrocracking, hydrodesulphurization and catalytic reforming with hydrogen at high pressures of 1750 – 2175 psi (12 – 15 MPa) and temperatures as high as 932°F (500°C).

Various theories and studies [3, 4, 5, and 6] have dealt already with this very subject and it is not the intent of this report to deal with that same matter. This report simply will show that the overlay in combination with the base material, within the scope of this development, have been subjected to a hydrogen disbonding test and no disbonding has occurred so that the overlay/base material researched here will be qualified for production use without any other further qualification. The three different base materials, Carbon Steel, 1 ¼ Cr/.5 Mo and 2 ¼ Cr/1 Mo, are the most popular choices of materials for piping, fittings and pressure vessels used in the oil and gas industry. For the large diameter, heavy wall pressure vessels used in the hydrogenation process, the most representative material is the 2 ¼ Cr/1 Mo.

Having the three materials, Carbon Steel (SA516-70 HIC plate), 1 ¼ Cr/.5 Mo and 2 ¼ Cr/1 Mo, subjected to hydrogen disbonding test is really a strong statement needed to prove the viability and credibility of the ElectroSlag Strip Overlay process. The new concept of applying this process in small confined interiors such as 10" (254 mm) diameter pipes with wall thicknesses as low as ¾" (19 mm), using 1 3/16" (30 mm) wide strip, is the ultimate proof of the viability of this process.

Hydrogen disbonding testing of the overlay interface with the parent material has been carried out in an autoclave with high pressure/temperature and in a hydrogen atmosphere. The tests are designed and modified to fall within the limits imposed by the base materials used as shown in Table 2.

TABLE 2

HYDROGEN DISBONDING TEST: "1 LAYER" ELECTROSLAG STRIP OVERLAYS						
MATERIAL OF TEST COUPON 3" dia. x .75 thk. (76.2 x 19 mm)	OVERLAY TYPE	THERMAL CONDITIONS °F/°C	TEST CONDITIONS			COUPON ID
			TEMP °F/°C	pressure psi/Mpa	COOLING RATE °F/°C PER HOUR	
SA516-70 (HIC PLATE)	ALLOY 625	AS WELDED	572/300	1595/11	390/200	CAP.P1.OES.30.7.1
SA516-70 (HIC PLATE)		PWHT 1150° ±25° (621° ±4°)				CAP.P1.OES.30.7.1SR
SA387-11	ALLOY 625	PWHT 1325° ±25° (718° ±4°)	752/400	1885/13		CAP.P4.OES.30.7.1SR
SA387-11	ER347					CAP.P4.OES.30.5.1SR
SA387-22	ALLOY 625		842/450	2175/15		CAP.P5A.OES.30.7.1SR
SA387-22	ER347					CAP.P5A.OES.30.5.1SR

6. Full Testing of Carbon Steel Plate and Elbows, 1 ¼ Cr/.5 Mo and 2 ¼ Cr/1Mo Plate ElectroSlag Strip Overlayed

As mentioned earlier in this report, the main intent is to prove the process, technique and equipment for ElectroSlag Strip Overlaying of pipe, fittings, and pressure vessels with interiors as small as 10" (254 mm) diameters and wall thicknesses as low as .75" (19 mm)

6.1 Testing of SA516-70 Plate (HIC Material) ElectroSlag Strip Overlayed WITH 316l, 317l, Alloy 400 and 625

6.2 Testing of 1 ¼ Cr/.5 Mo Plate ElectroSlag Strip Overlayed with 317L, 347, Alloy 600 and Alloy 625

6.3 Testing of 2 ¼ Cr/1 Mo Plate ElectroSlag Strip Overlayed with 347 and Alloy 625

All tests, penetrant, ultrasound, bend, hardness, macrography, corrosion ASTM G-48 and 262, ferricyanide, and hydrogen disbanding were good.

6.4 Testing of 12", S160, 90° LR Elbows Hot Formed from 12" S160 SA106B Pipe ElectroSlag Strip Overlayed with "1 Layer" and "2 Layer" Alloy 625

The idea of being able to overlay straight pipe and then make it into 90° elbows is very appealing due to the very significant cost advantage. The two elbows shown in Fig. 5 were hot formed from the same pipe with one difference: the number of layers. Elbow A has "1 layer" Alloy 625 and Elbow B has "2 layer" Alloy 625. Both were performed with the ESSO process. Full testing performed on the hot formed, electroslag weld overlayed elbows was performed with excellent results.

For a full understanding of the low dilution advantages provided by the ESSO process, in Table 3 a full comparison of strip chemistry (start material) versus "1 layer" ESSO deposit is presented. It is very obvious that with "1 layer" ESSO deposit we come very close to the chemistry of the solid corresponding corrosion resistant material. Some dilution takes place but “no dilution” or “too low dilution” would mean no bonding.

TABLE 3

CHEMISTRY COMPARISON OF STRIP VERSUS “1 LAYER” ESSO DEPOSIT ON CARBON STEEL, 1 ¼ Cr/.5 Mo AND 2 ¼ Cr/1 Mo PLATE												
ELEMENT	316L		317L		347		ALLOY 600		ALLOY 625		ALLOY 400	
	STRIP	OVERLAY	STRIP	OVERLAY	STRIP	OVERLAY	STRIP	OVERLAY	STRIP	OVERLAY	STRIP	OVERLAY
C	.018	.03	.009	.015	.011	.03	.01	.01	.02	.03	.03	.09
Cr	18.25	16.8	20.30	17.3	20.00	17.0	20.60	20.4	21.43	19.0	.01	.04
Ni	12.52	11.0	14.30	13.0	10.00	9.4	72.30	67.0	61.9	58.0	65.4	64.3
Mo	2.87	2.4	3.4	3.2	.05	.12	-	-	8.71	7.00	-	-
Nb+Ta	-	-	.02	.01	.82	.60	2.68	1.2	3.69	2.9	.01	.01
Fe	-	-	-	-	-	-	.67	8.3	3.69	12.00	.20	2.8
Cu	.07	.06	.09	.05	.10	.02	.01	.05	.01	.30	28.7	28
Si	.30	.48	.25	.35	.40	.62	.11	.33	.12	.50	.10	.46
Mn	1.73	1.30	1.72	1.20	1.27	.90	3.16	2.52	.23	.25	3.3	2.28
N	.051	.05	.050	.028	.015	.018	-	-	.009	-	-	-
Ti	-	-	-	-	-	-	.35	.12	.21	.20	.23	.01
S	.002	.01	.006	.01	.001	.01	.003	.01	.003	.01	.002	.001
P	.013	.03	.011	.03	.018	.03	.004	.01	.006	.01	.005	.01
FERRITE DL	6.5	4.0	7.5	4.2	14.0	4.5	-	-	-	-	-	-
PRE	28.3	24.7	31.5	27.9	-	-	-	-	50	42.1	-	-

NOTES:
1. STRIP SIZE: 30 x .5 mm (1 3/16” x 3 /64”)
2. PRE (PITTING RESISTANCE EQUIVALENT) = %Cr + (3.3 X %Mo)
3. FERRITE “DL”: CALCULATED BY DELONG
4. OVERLAY CHEMISTRY AT 3/32” (2.4 mm) ABOVE FUSION LINE.

7. Conclusions

7.1 The high quality ElectroSlag Strip Overlay process with high deposition and low dilution rates is one of the most cost effective surfacing methods available to us today.

7.2 The development of a small ElectroSlag Strip Overlay device capable of overlaying pipe interiors as small as 10” (254 mm) diameter, allows almost instant availability of small and medium quantities of overlayed pipe not available otherwise from large steel mills.

7.3 The manufacture of 90° elbows from highly cost effective ElectroSlag Strip Overlayed pipe gives both the manufacturer and the end user a much more competitive product with very fast turn around time.

7.4 In theory, disbonding of overlayed products working in high pressures/temperatures and a hydrogen environment is a possibility no matter what overlaying process is used. Disbonding can occur when hydrogen migrates through the overlay material towards the base material. At the interface of the two materials, the solubility of hydrogen changes. This differential in solubility yields the “storage” of hydrogen at the interface which could lead to the appearance of hydrogen “pockets” and ultimately disbonding. This report prove that within normal conditions with the variety of overlays performed with the ESSO process tested on three different base materials, no disbonding occurred.

7.5 The very low dilution rates achievable with the ESSO process makes it possible to produce one layer of high quality deposits with significant cost savings.

7.6 The ESSO process yields such technical and economical advantages that it is the prime candidate for replacing a great number of existing cladding or overlaying systems in a large number of applications.

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