Tailor Welded Coils: Hot-Dip Galvanizing a Variable Thickness, Multi-Strip Welded Coil

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Abstract:

Three cold rolled, annealed, uncoated steel coils of differential thickness and strength grades were joined autogenously, edge to edge, in a laser butt-welding process on TWB Company's tailor welded coil line. This multi-strip, welded coil was then hot-dip galvanized continuously inline at Spartan Steel Coating. Both of these companies have facilities located in Monroe, Michigan which is where the welding and coating trial took place.

The purpose of this trial was to determine if a multi-thickness coil could be coated in an inline process. The base material and coating properties before and after the coating process were measured. The team evaluated the base material and coating properties and characteristics that would predict intended performance. This initial trial proved the concept and eased uncertainties of processing a differential thickness coil through a production galvanizing line.

Figure 1

HDG tailor welded coil

Introduction:

Tailor welded blanks and coils are made from individual sheets or slit coils and can combine various thickness, grade, and coatings as required by the end used product into a single sheet or coil. TWB Company expanded its core business of tailor welded blanks for use in sheet-fed transfer and tandem press lines to joining entire coils together, edge to edge. Tailor welded coils are used in coil-fed processes such as blanking, progressive die stamping, transfer press stamping, and roll forming operations.

The advantages of joining coils of steel made up of differential thicknesses, strength grades, and or coatings have been recognized and accepted by stamping and fabricating manufacturers. High volume automotive vehicle programs currently have parts stamped from tailor welded coils in production today. This paper documents the steps of this trial and the results show that tailor welded coils of different thicknesses can be coated after welding.

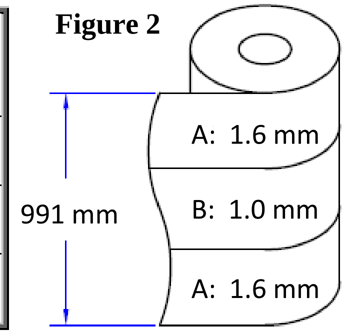
Materials:

Table 1 below lists the individual coil strip information used to produce the tailor welded coil. Finished coil: 991 mm wide x 630 meters length at 6.5 metric tons (illustrated in Figure 2).

Table 1

	Gauge (mm)	Position	Material	Width (mm)	Ts (MPa)	Ys (MPa)	Uniform Elong. (%)	Total Elong. (%)
"A"	1.6	Outer Strip 1	CR HSLA	248	422	327	19.2	29.8
"B"	1.0	Center Strip	CR LC CQ	495	318	188	23.4	40.1
"A"	1.6	Outer Strip 2	CR HSLA	248	422	327	19.2	29.8

Figure 2



Chemical analysis for the uncoated, base material heavy gauge ("A" strip) and light gauge ("B" strip) is shown in Table 2. Bulk chemical analysis was performed by Glow Discharge-Optical Emission Spectrometry (GD-OES) in accordance with LECO GDS-850A.

Table 2

	Elements (all units are % by weight)												
	C	S	P	Si	N	Mn	Cr	Ni	Mo	Al	Cu	Ti	Nb
"A"	0.07	0.007	0.011	0.03	0.003	0.70	0.04	<0.02	<0.02	0.057	0.03	<0.008	0.021
"B"	0.04	0.007	0.014	<0.02	0.007	0.21	0.04	<0.02	<0.02	0.057	0.04	<0.008	<0.008

Welding Process:

One precision slit 1.6 mm thick coil and one precision slit 1.0 mm thick coil were loaded onto TWB's tailor welded coil line and simultaneously fed through individual, inline leveling stations, with capability to handle material strengths up to 980 MPa at a thickness of 3.0 mm. The individual coil strips then advanced into the fixed-position 6 kW fiber laser powered welding station via a patented pressure roller drive system where the coil edges were joined. TWB maintains a laser spot size diameter for welding of approximately 0.75 mm by managing a precise combination of fiber diameter, collimator and final focus lens sizes. The two-strip welded coil exited the weld station and was recoiled under tension. This two-strip welded coil was passed through the coil welding line a second time, where the third strip (1.6 mm) was added in the same process as described above.

Coating Process:

This coil was coated on a fully automated, continuous flow hot-dip galvanizing line, utilizing closed-loop control systems. After successfully resistance seam lap welding to the previous single thickness coil, the variable thickness coil passed through a 3 stage alkaline cleaning system and into a four stage vertical annealing furnace. The first stage pre-heated the coil. The direct fired furnace in stage two further heated the coil strip to ~650 degrees C. Stage three's radiant tube furnace then raised the coil strip temperature to its annealing temperature of ~830 degrees C for one minute. This was followed by a jet air-cooling section that reduced the coil strip temperature to ~470 degrees C as it entered the zinc pot.

The coating weight target was 50 g/m^2 for both the top surface (weld step side) and bottom surface (flush side) of the coil. The top and bottom side air knife pressure range was 3.3-3.8 psi. The air knife distance for the top and bottom was set to 15.7 mm with a line speed of 61 meters/minute.

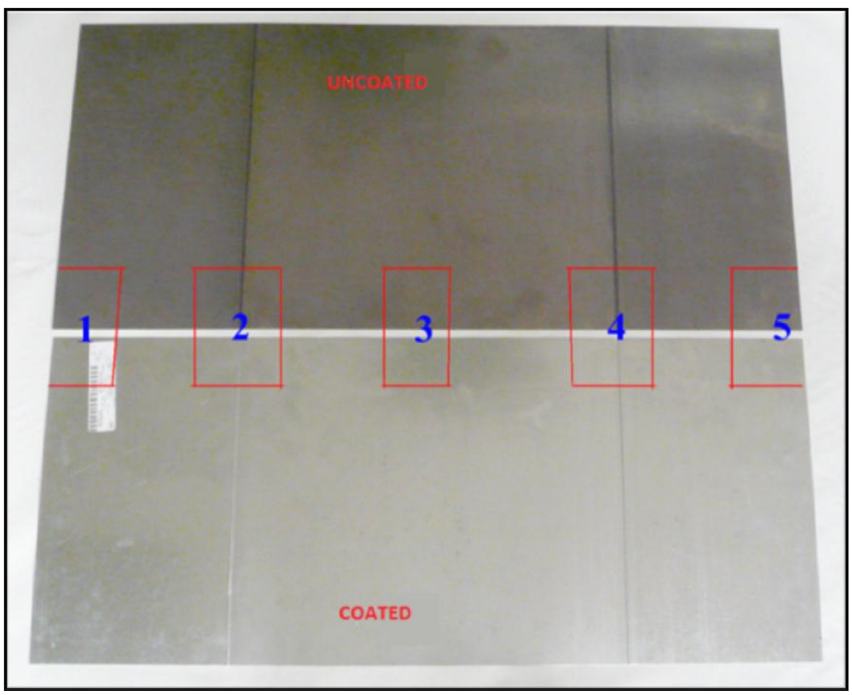
After zinc application, the variable thickness coil entered an after pot air cooling tower where the temperature was reduced to ~238 degrees C (Figure 3). A finishing water quench further reduced the coil strip temperature to ~45 degrees C. Although available, a skin pass mill operation and a tension leveling operation were not utilized for this coil. Finally, an electrostatic oiler applied a standard quantity of mill oil to the coil.

Figure 3

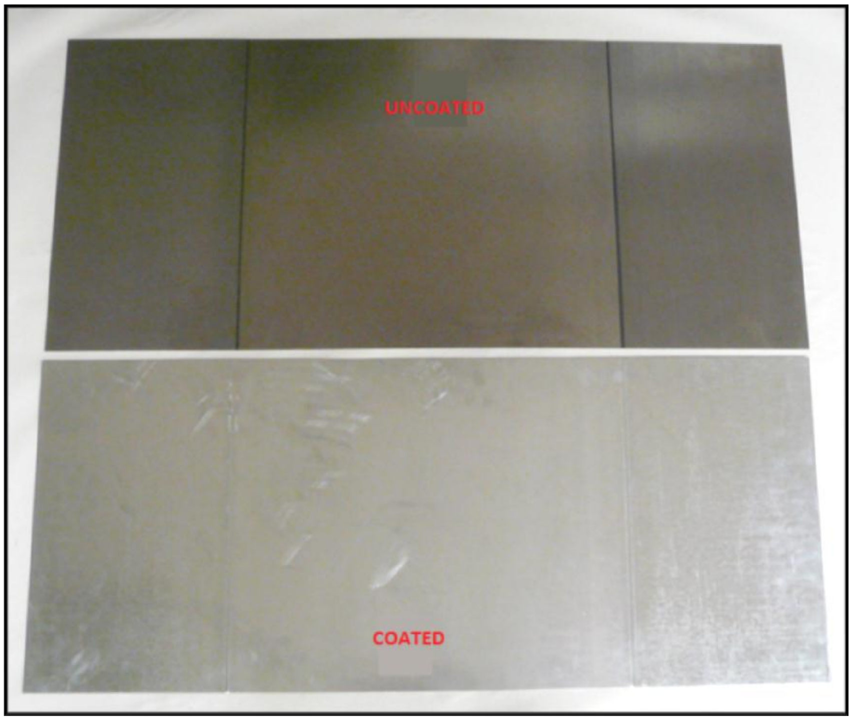
Tailor welded coil exiting zinc pot

Results:

The following photo-macrographs show sections and analysis locations for the as-welded and hot-dip coated samples.



Over-all photo of a section of the as-welded uncoated coil and a section after coating; weld step side (top) is up.



Over-all photo of a section of the as-welded uncoated coil and a section after coating; flush side (bottom) is up.

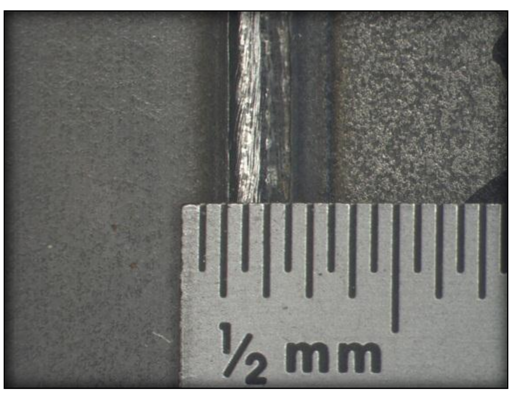


Photo-macrograph of uncoated step side laser weld.

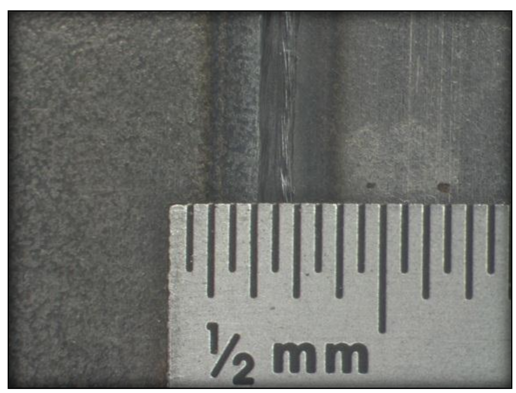


Photo-macrograph of uncoated flush side laser weld.

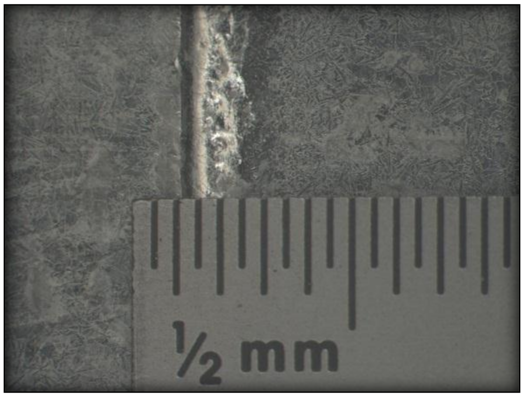


Photo-macrograph of <u>coated step side</u> laser weld.

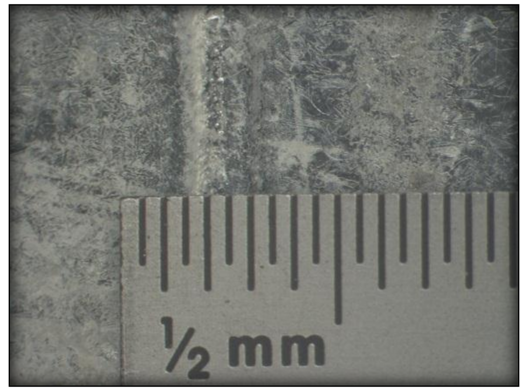


Photo-macrograph of <u>coated flush side</u> laser weld.

Multiple areas of the coated coil were tested for coating adhesion per ASTM A653 Section 8, correlated to a "0 t bend". All areas passed with no flaking evident. The following photo-macrographs show coated only bend tests as well as cup test sections for the coated and as-welded samples for comparison purposes.

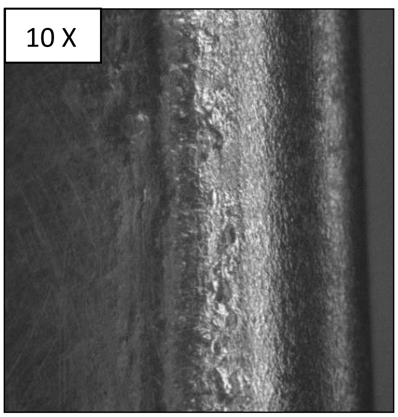


Photo-macrograph of laboratory bend test of <u>coated step side</u> laser weld.

Photo-macrograph of "Olsen Cup" test of weld seam for coating <u>after</u> welding.

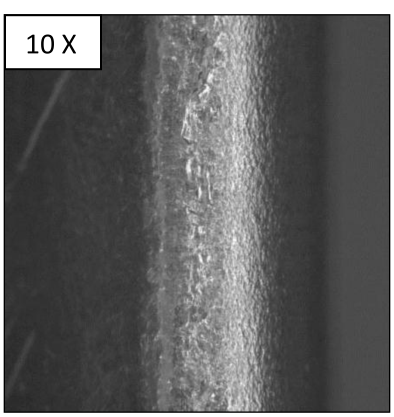


Photo-macrograph of laboratory bend test of <u>coated flush side</u> laser weld.

Photo-macrograph of "Olsen Cup" test of weld seam for traditional welding of two separate coated materials.

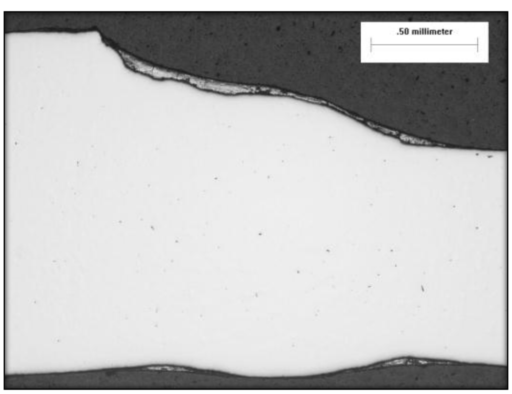
Coating weight distribution across the coil width due to the differential thickness of a tailor welded coil and the ability to coat the weld seam was a major concern. The air knife pressure and distance were set to the thicker material with the previously stated target coating weight of 50 g/m^2 (7 microns thickness). During the coating process, coating weight measurements were taken along coil edges and throughout the center strip, top and bottom, in approximate 14 meter increments for a total of 44 data points at each location; these results are shown in Table 3.

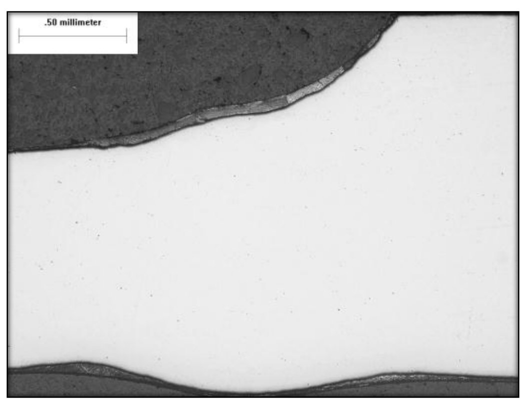
Table 3

	Coating Application					
	Top Operator Edge	Top Center	Top Drive Edge	Bottom Operator Edge	Bottom Center	Bottom Drive Edge
Inline Coating Weight Avg. (g/m^2)	57.9	59.4	55.5	42.3	54.9	57.1
Standard Deviation	2.8	3.7	1.8	3.1	2.5	2.3
Lab Results (g/m^2)	70.2	58.5	62.8	55.1	54.5	63.5
Lab Optical Measurements (microns)	9.8	8.2	8.8	7.7	7.6	8.9

Laboratory analysis of the coil coating weight shows that the top center with the thin material can be successfully coated to a target weight set for the thicker material. Although the variation of the coating weight on the thin material was larger than that of the thick material, it suggests that the thinner material would be coated heavier. Coating weight variation for coils with differential thicknesses outside that of the 0.6 mm trial coil should be considered in future development projects.

Pictured below are photo-micrographs of transverse sections through the weld seam showing the coating coverage across the weld area.





Mechanical Properties:

Table 4 below shows mechanical properties in the uncoated and coated sample sections tested.

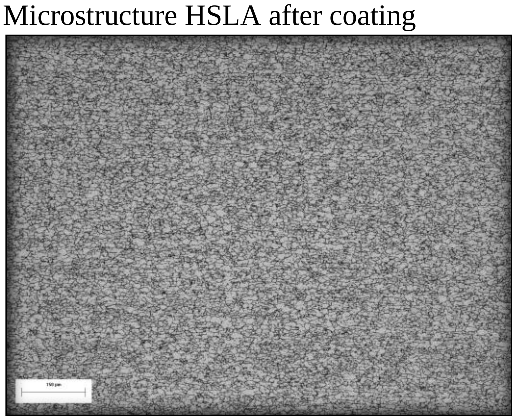
Table 4

Location	Uncoated Mechanical Properties			
	Tensile Strength (MPa)	Yield Strength (0.2% offset) (MPa)	Uniform Elongation (%)	Total Elongation ~50 mm (%)
"A" Strip 1	419.2	312.3	19.1	29.6
Across Weld (3 Location Avg.)	325.2	213.7	10	20.8
"B" Strip	318.5	187.5	23.4	40.1
Across Weld (3 Location Avg.)	319.2	214.2	9.9	20.8
"A" Strip 2	424.0	341.3	19.3	29.9
Location	Coated Mechanical Properties			
	Tensile Strength (MPa)	Yield Strength (0.2% offset) (MPa)	Uniform Elongation (%)	Total Elongation ~50 mm (%)
"A" Strip 1	413.0	308.9	19.3	30.6
Across Weld (3 Location Avg.)	338.1	259.7	10	19.6
"B" Strip	337.2	241.3	23.7	36.9
Across Weld (3 Location Avg.)	339.2	234.2	9.8	19.5
"A" Strip 2	415.8	326.9	18.6	30.2

Generally, cold rolled steel coils are introduced into a continuous hot-dip galvanizing line in the "full-hard" condition. For this trial, however, the material used had been previously annealed. Analysis of the resulting mechanical properties shows that the HSLA material softened slightly, < 2% tensile strength with corresponding changes in total elongation. The low carbon CQ material hardened; the tensile strength increased ~ 6% while the yield strength increased appreciably by > 28%, there was a corresponding reduction in total elongation. The tensile strength across the weld seam increased slightly by 4% to 6%. All fractures were outside the fusion zone, in the thinner material.

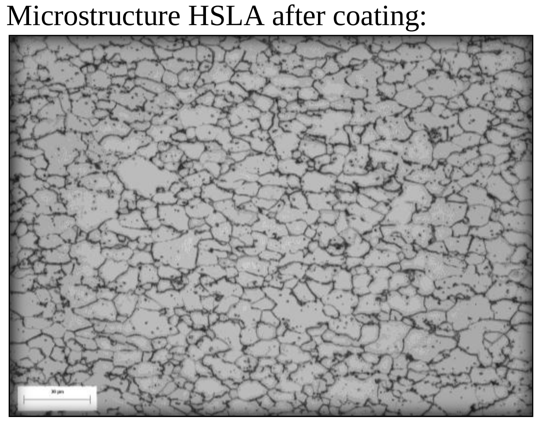
Microstructures:

Microstructure HSLA after coating



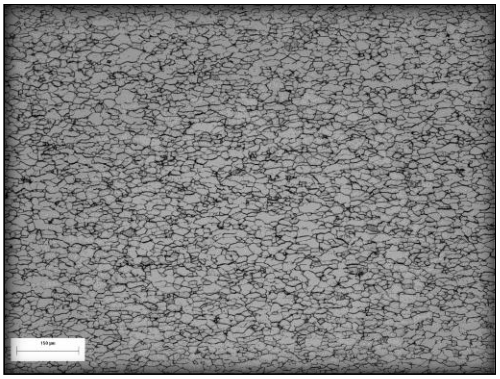
Etched condition 100x

Microstructure HSLA after coating:



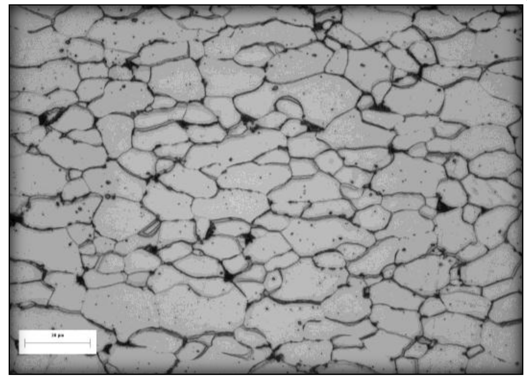
Etched condition 500X

Microstructure Low Carbon CQ after coating:



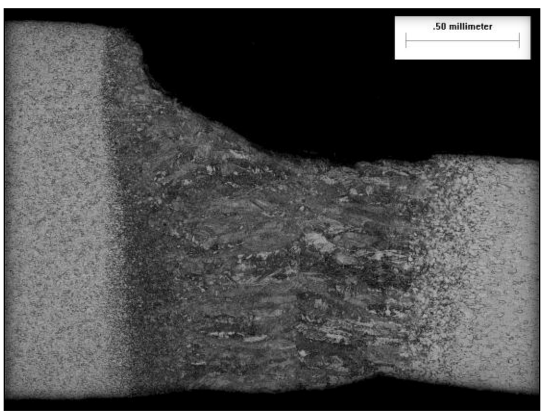
Etched condition 100x

Microstructure Low Carbon CQ after coating:



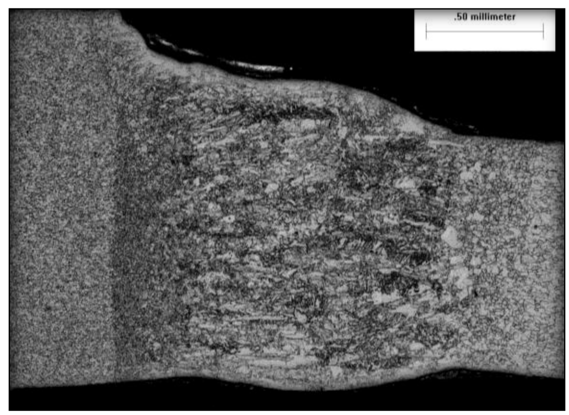
Etched condition 500X

Microstructure uncoated weld seam:



Etched condition 50x

Microstructure coated weld seam:

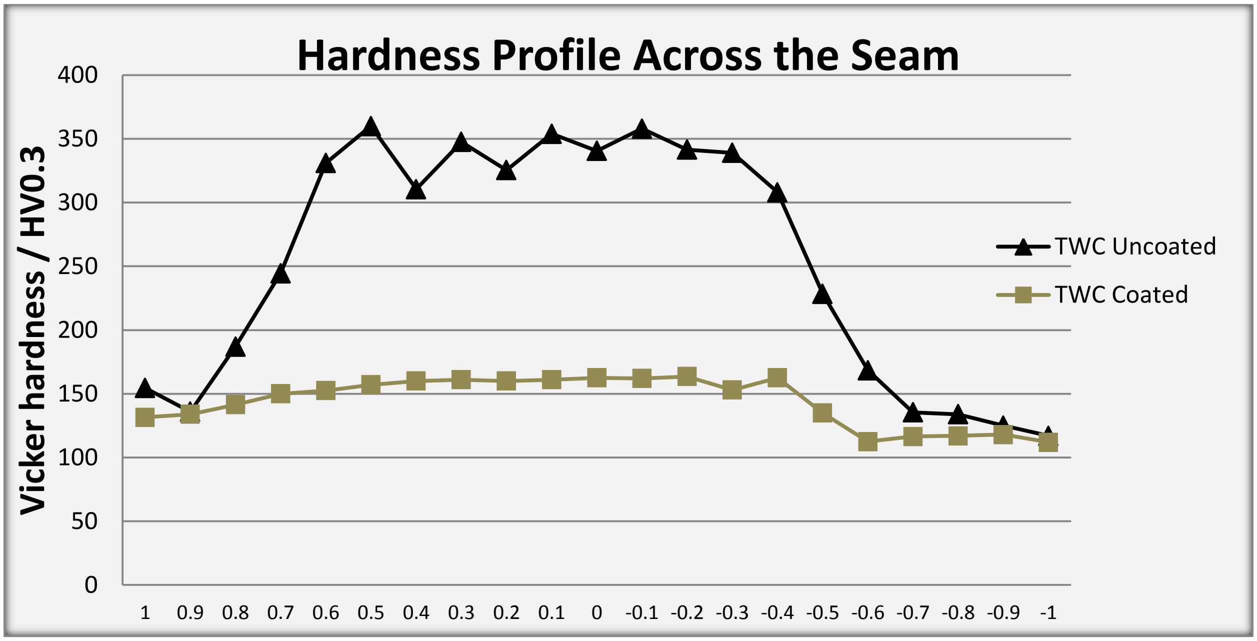


Etched condition 50X

Hardness:

Chart 1 shows the Vickers micro-hardness traverse through the weld seam in both the uncoated and coated conditions. The coated sample has a decrease in weld peak hardness due to the thermal cycles used in the galvanizing process. This softening of the weld seam has interesting potential when it comes to forming Advanced High Strength Steel (AHSS) grades made from tailor welded blanks and tailor welded coils.

Chart 1



Conclusions:

- A tailor welded coil of differential thickness and strength can be successfully processed through a continuous hot-dip galvanizing line.

- On a micro scale the process tempered the weld seam hardness from ~Rc 37 to ~Rb 85 (HV 0.3 360 to 166); this is a significant advantage to any subsequent stamping/forming operation.

- The adhesion of the coating to the weld seam and base material met all requirements.

- The weld seam step was uniformly coated.

- With a differential thickness of 0.6 mm, the coating weight on the thinner material was in the set target range.

- Coating cold rolled, previously annealed HSLA material did not significantly affect its mechanical properties. Conversely, the yield strength on the low carbon CQ material showed a substantial increase.

Future Development:

- Tailor welded coils should be processed through other continuous hot-dip coating lines, particularly those for Aluminum Silicon.

- Continuously hot-dip galvanize tailor welded coils with strip thickness differential other than 0.6 mm, using the same balanced configuration of thick outer strips and a thin inner strip.

- Explore processing tailor welded coils for pre-painted applications or other pre-treatments.

- Investigate galvanizing different tailor welded coil configurations such as thin outer strips or a tailor welded coil made up of just two strips, thick to thin.

- Tailor weld a coil starting with full-hard strips; then hot-dip galvanize.

About TWB:

TWB is North America's leading tailored solutions provider and is committed to providing global solutions to customers through people, innovation and technology.

TWB Company and Spartan Steel Coating are separate joint venture companies that share a common owner in Worthington Industries.

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