Performance of Paint Coating on Galvanized Steel in Coil Coating Line

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Abstract

Paint coatings are specialty products, which are used to give long term protection under a broad range of corrosive conditions, extending from atmospheric exposure to full immersion in strongly corrosive solutions. A paint coating provides them little strength, yet they protect galvanized steel, so that the strength and integrity of steel can be maintained. The quality of paint coated hot-dip galvanized (HDG) steel sheets against aggressive environments depends on several factors linked to galvanizing, tension regulation at various sections, concentration of alkaline bath and chemical conversion coating bath, hydrogen evolution and baking temperature of primer and topcoat ovens. Each component gives a contribution to the final anticorrosive performance of the coated product.

1. Introduction

The coil coating is a continuous and highly automated process where paint coating is applied over galvanized steel to protect and decorate. This type of process is also called as a duplex coating.

Initially paint coating were applied on the steel by application with brushes/ rollers. After wards air spray and airless technology was developed. There were many limitations noticed in these technologies, such as lower production, nonuniform thick coating and higher manual work. In 1940's, first coil coating line was started in Europe, it became more popular due to its basic advantages are ;

- Higher production.
- Highly sophisticated and computerized controlled system.
- Environmental benefits and energy saving.
- More consistent properties.
- Less wastage of coating material.

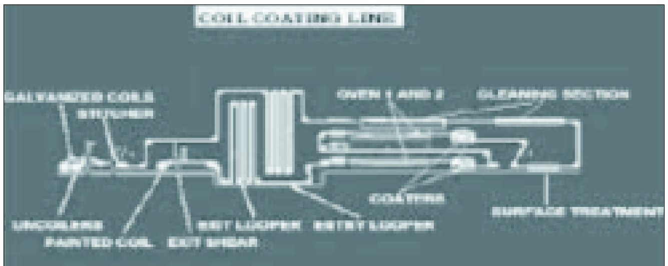

Fig: 1 The flow diagram of typical coil coating line.

When paint and galvanized steel are used together, the corrosion control provided is superior to either system used alone. The galvanized coating protects the base steel, supplying cathodic and barrier protection and the paint slows down the rate at which the zinc is consumed, greatly extending the life of the galvanized steel. Once the paint has been weathered down or damaged, the zinc is available to provide cathodic and barrier protection to avoid rust after paint peel off. Because of this synergistic effect for a duplex coating it provides corrosion protection 1.5 to 2.5 times longer than the sum of the lifetimes of zinc and paint used individually. For example, if the galvanized coating life on steel is expected to 15 years and the paint coating life on steel is expected to 5 years, the galvanizing and paint together gives life of 35 years, which is 1.7 times the sum of both systems.

Basic principle of coil coated line is that strip travels through the various process sections in a continuous manner without ever stopping or changing speed. As a result, the material being coated has extremely consistent properties. The continuity is achieved through the use of entry and exit loopers. The entry looper allows an operator to stop the entry end for splicing in another coil while the coil is being processed continuous to run the process section.

During a typical tandem line process strip metal is unwound from a coil placed on uncoiler and passes through a 'wet section' where it is cleaned and chemically treated .Once dried, the metal strip passes through a coating section for the application of primer first coating. After the first coating application the metal passes through a centenary oven for curing and is cooled by water quenching. The top finish coat is applied by similar method and the metal enters the second centenary oven for curing.

Although the exit looper maintain continuity of process section. It performs an opposite function from that of the entry looper; it absorbs the material from the line which allows the exit section to stop for coil cutting at required length on recoiler. The typical continuous coil coating line is shown in fig 1.

Any deviations of the processing parameters reflect in the final quality product. This can be confirmed by testing of various properties.

Corrosion resistance is one of the important parameter to check the quality of the paint coating.The first factor which affect the performance of coating line is the setting of the tension regulation at different sections, as any deviation from optimized value lowers the production, tending to material rejection and equipment damages. The lower tension, gives side tracks at chemical section, scratch lines at bottom in baking ovens of process section and collapsing of coil after recoiling at exit section.

However if tension is higher, it affects quality, like scratch line at top in baking ovens of process section and Vnotch formation at recoiler of exit section. Second factor is the setting up the concentration of alkali and conversion coating in chemical section bath, if lower the concentration of chemicals causes coating to fail. However if the concentration is higher, quality qualifies all the performance of any test. Third factor which affects the paint quality in coil coating line is the baking time in the ovens, insufficient baking time causes craters in paint due to hydrogen evolution. Fourth factor is the setting of baking temperature in the primer oven and the topcoat oven.

If the temperature is lower than desired, peel off of paint taken place due to the poor crosslinking, however if the temperature is higher than desired, coating burns off, it's color changes and gloss is affected.

Progressive developments in coating systems have resulted in long life products for a wide range of applications, most importantly cladding materials for industrial, commercial and residential buildings. Today's architectural coatings have been formulated progressively over more than 20 years, to meet the general critical performance specifications established by western industrialized nations. The coil coating has become a significant market for the chemical and coating industry within the last half of the twentieth century.

Coil coated products are used in a variety of industries including building and construction, appliances and automotive parts. There are a wide variety of coatings applied to metal coils. These includes polyesters, acrylics, alkyds, vinyl, plastisols and PVDF.

2. Preparing of substrate for paint coating

The continuous coil coating process is equipped with a sophisticated strip cleaning section. This section provides all the surface preparation required for good paint coating and is able to handle a wide variety of unwanted surface contaminants such as white rust, oil and dirt. There are two keys for proper surface preparation:

* Alkaline solution cleaning
* Conversion coating

2.1 Alkaline solution cleaning

The preparation of metal surface is the first process in any coil coating line. The method used to clean the metal and create an oil free surface is all pretty similar to those used on some of the earliest coil coating lines.

The metal travels through a series of tanks that serve to both cleaning and rinsing the surface. The tanks are generally equipped with a high pressure pump, feeding a series of spray nozzles that clean both the sides of the moving strip.The majority of the lines use a basic alkaline solution for the cleaning of the metal. The soft bristled nylon bush rolls are provided within the tanks to act as a mechanical brushing. Concentration of the alkaline solution varies with the oil or contaminants on the surface of the incoming raw material.

2.2 Conversion Coatings

The purpose of conversion coating is to allow good mechanical bonding, which provides a protective layer to the metal. This chemical treatment is designed to react with and modify the metal to produce a surface suitable for painting and to enhance paint adhesion. This conversion coat also provides protection to the metal from exterior corrosion. The strip continues into thechemical treatment in one of two ways :

the first method is to pass the strip through a spray or dip tank and the second, and most environmentally safe method, is to use a chemical coater. In using a chemical coater for this part of the process the strip passes through the coating machine which applies a thin layer of chemical film on both sides of the strip. The chemical coating machine consists of a series of rolls that support the strip through the machine and utilizes a pick-up roll and a rubber applicator roll to apply the chemical to the strip. After exiting the chemical coater, the strip moves directly into a drying oven, which dries and eliminates any moisture from the strip.

3.Test conducted to study the performance of the coated product

3.1 Impact test :

The resistance of the paint to mechanical damage has been determined by the falling weight test as per the ASTM D 2774-84 standards. This method is used to check for cracking or loss of adhesion at areas other than the impact area.

The samples to be fixed at the bottom of the equipment by the help of two fixtures. According to the above standard weight of 4.76kg ± 28gm is allowed to fall freely from a height of 57cm.

3.2 Bending adhesion test :

The adhesion test is carried out as per ASTM D4145-83, for assessing the adhesion of coating films to metallic substrates, to make it 1800 bend by applying force in a bending machine, the sample to be folded twice times the thickness of the substrate for assessing adherence of the paint coating. If it is failed after 2T then it should be considered as a bending adherence test failure.

3.3 Flexibility test :

The flexibility test is carried out as per ASTM D522 standard. It is used to determine the flexibility resistance to cracking of paint coatings on substrates of sheet metal. A conical mandrel is used for the test. The coated panel bends over the mandrel through 180 degree in one second. Subsequent to bending, the paint film is examined for cracking and delamination from the substrate.

3.4 Hardness Test (Pencil test) :

The hardness of the paint to mechanical damage has been determined by the pencil test as per the ASTM D 3363-74 standards. This method is used to check the hardness. The samples to be fixed at the bottom of the equipment by the help of two fixtures. According to the above standard, the specified high hardness is 2H minimum. For this test faber castle pencil is used.

3.5 Chemical resistance test :

The chemical resistance of paint to be evaluated by immersing the painted sample in distilled water, 5 % aqueous solution of NaOH and 5 % aqueous solution of H2SO4 solution for 24 hours. Samples are evaluated for evidence of detrimental chemical attack. Evaluations of samples generally indicate variation in gloss, color and adhesion, and monitoring of problems like blistering, disbondment, chalking and cracking is done.

3.6 Salt spray test :

This test is intended to reproduce the corrosion that occurs in atmospheres containing salt. The test is conducted according to ASTM standard B117. Testing of this type is considered useful when evaluating the behavior of materials subjected to a marine environment. Selected paint samples to be exposed to salt spray fog in a customized sealed chamber. 5% of NaCl salt solution is taken as the standard to generate the salt spray. Other parameters like temperature, air pressure, orientation of the sample etc. are maintained. The progress of corrosion to be evaluated by visual examination after a given interval.

3.7 Heat resistance test :

Standard size of sample is to be kept inside the muffle electrical furnace for 12 hours with a temperature of 1250C. Every hour the sample to be taken out for inspection. observe for blistering, change of color and gloss.

3.8 MEK (Methyl ethyl ketone) Test :

For this test, cotton wool is absorbed Methyl Ethyl Ketone chemical, applying 1 Kg load on the sample by cotton wool and rub it up by thumb for 100 times. Re-soak cotton wool in a MEK solution after every 25 rubs, observe paint getting peel off.

4. Coating characteristics.

In coating line, two coats of paint is more popular on galvanized steel. Generally, conversion coating of 2-4 micron is given in chemical section. First coat of primer epoxy is applied on top and bottom side with 3-5 micron in a first roll coater. Second finish coat of either polyester, PVDF or plastisol is applied on top surface with 15 - 20 microns thickness and backing coat of 9-10 micron in second roll coater.

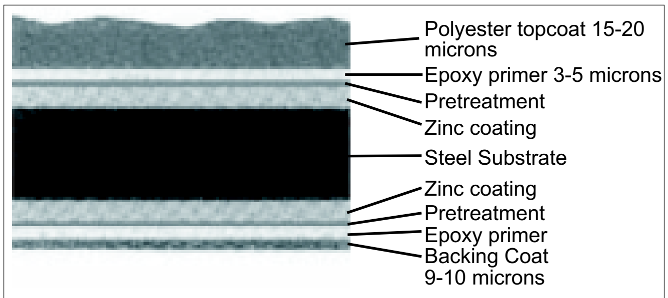

Fig: 2 Schematic arrangements of coating structures.

The schematic arrangements of coating structures is shown in Fig; 2.

5.0 Factor affecting the performance of paint coating.

Some of the most important parameters which affects the performance of paint quality are tension regulation, chemical bath concentration, hydrogen evolution and PMT of baking ovens. The detail descriptions of these factors are given below:

5.1 Effect of tensions at various section.

The quality of the painted coil obtained depends strongly on the tension at various points in the coating line. Three points at which the level of tension decides the coating qualities are; entry section, processing section and exit section. To ensure strip at centre of the various rolls, proper tension is required to grip between strip and roll. Its value measured in Kg. and varies to 3 - 10 % of yield strength of low carbon steel from section to section. Various trial tests were carried out in one of the coil coating line by varying tension at various points. It was done by processing dummy skin passed galvanized coils of different thickness during initial start of the plant. It was observed that lower tension in entry section leads to side tracking in chemical section, because of lesser stress.

In process section when tension was low, scratch line at bottom surface of the steel strip in baking oven was observed. However, when the higher tension in process section leads to scratch line at top surface of steel strip in baking oven. It was also observed that at exit section when tension of recoiler was low, coil got collapsed due to low radial pressure between wraps and lower frictional stress between slippages. Lower friction means more susceptible to interwrap movement, this leads to coil collapse. However, higher tension at recoiler leads to the plastic deformation of steel strip as applied stress is exceeded than the yield stress, which formed the V-notch at the ID of

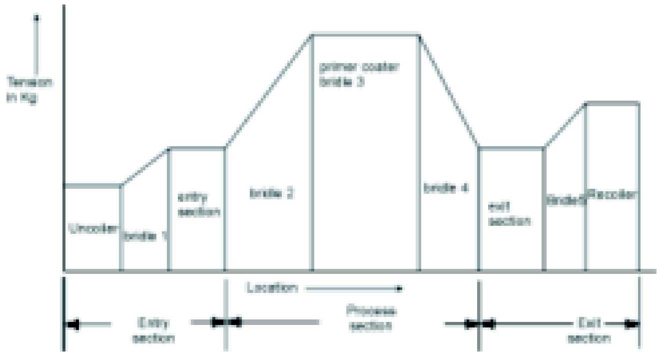

Fig 3: Schematic summarization of the tension profile in coil coating line.

coil.

Same exercise was carried out on different thicknesses and line speed by varying tension for optimizing the parameters.

Based upon the experimental data collected during trials, it is now possible to plot schematic summarized tension profile at various points, which is shown in fig : 3.

5.2 Effect of alkali and conversion coating bath concentration

Alkali bath concentration is very critical parameter to maintain the coating quality of the coil. Various trial tests were carried out in one of the coil coating line by varying concentration of alkali and conversion coating baths.

When the concentration of chemical baths was lower, paint defects like delamination, paint peel off and blistering was observed. It was also observed that further increase in its concentration, the paint quality successfully passed in all the tests.

Same exercise was carried out on different thicknesses and line speed by varying alkali and conversion coating bath concentration for optimization of parameter.

Some of the test results of before and after optimized concentration are shown in Fig: 4, 5, 6 and 7.

5.2.1 Bending Adhesion Test

Two paint coated samples were tested for adhesion test under bending machine in 2T with 180 degree. Fig: 4 indicated that the coated film removed from the substrate and it's failed this test. Good coated film was observed in another sample and shown in Fig: 5.

Coating Peel Off

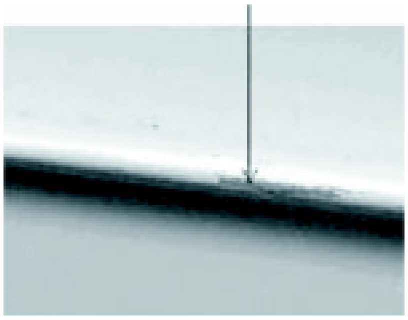

Fig: 4 Paint Coated film removed after bending test at low conc. (before optimized conc.)

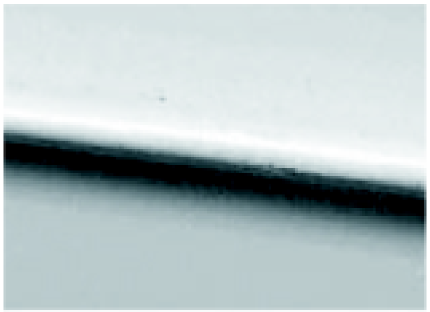

Fig: 5 Good painting quality after bending test (after optimized conc.)

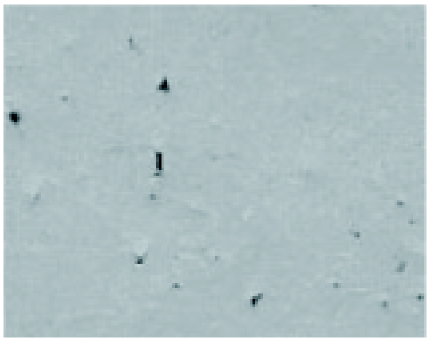

Fig: 6 Blistering observed after salt spray test at 300hrs with low conc (before optimized conc.)

Fig: 7 No significant corrosion was observed after 700hrs (after optimized conc.)

5.2.2. Salt spray test

The paint coated samples were tested for salt spray test. The result indicates the formation of corrosion products like rust, and blistering at various time intervals. The test was carried up to 900 hours. Figure. 7 and 8 depicts the condition of coils after 300 hours and 700 hours of salt spray exposure.

5.3 Hydrogen Evolution (Crater)

In hot dip galvanizing process, hydrogen gas is being purged into the annealing furnace, to clean the steel for zinc coating. However some of the hydrogen atoms remain intact with the steel before dip into the zinc bath and gets dissolved in the steel after the galvanizing. These dissolved hydrogen atoms had no time to escape from the material before the process of painting. During baking of the painted steel, these hydrogen atoms are converted to the

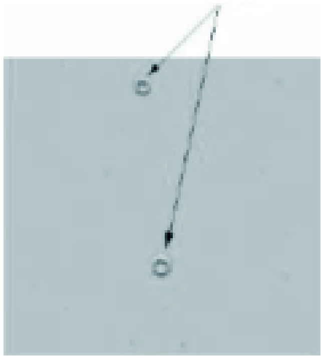

Fig. 8: Craters due to H2 evolution

molecular hydrogen, which is connected with a rapid local increase of the gas pressure, hydrogen gas delaminated the zinc layer from the steel. The hydrogen gas expands and escapes through the soft layers to the surface and causes appearance and crater.

Fig. 8 shows the craters formation due to H2 evolution.

5.4 Effect of Peak Metal temperature in primer oven and top coat oven.

Peak metal temperature in a oven is also a important key parameter which decides the paint quality.

Various trial tests were carried out in one of the coil coating line by varying PMT of both primer and top coat ovens.

When PMT was lower than the optimized value, paint defects like blistering, delamination and poor adhesion were observed. When the PMT was higher than optimized, defects like low gloss retention, paint burning off, paint fade were observed.

Same exercise was carried out on different thicknesses and line speed by varying PMT of both primer and top coat ovens for optimization.

Fig 9: Bending adhesion test fail at low PMT in primer oven. (before optimized temperature.)

Fig 10: Hardness (Pencil) test failed at high PMT in primer oven (before optimized temperature).

Some of the test results of before and after optimized PMT are shown in Fig : 9, 10, 11, 12 and 13.

5.4.1. Bending Adhesion Test

The paint coated samples were tested for adhesion test under bending machine in 2T folded in 1800. Fig : 9 shows that the paint got peel off when PMT of primer oven was low.

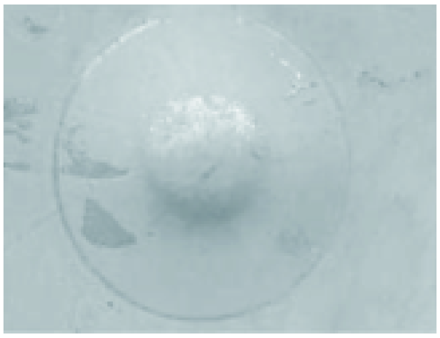

Fig 11: Impact test failed at high PMT in Top coat oven (before optimization.)

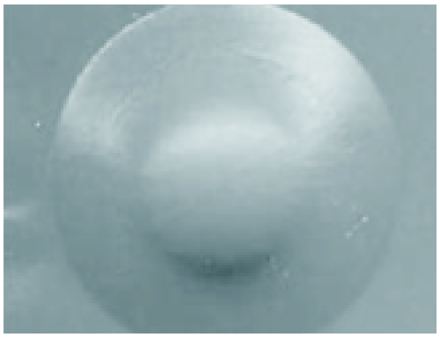

Fig 12: Impact test passed at optimized PMT in Top coat oven (after optimized conc.)

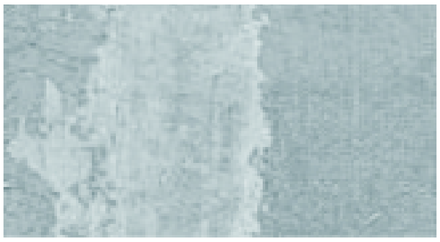

Fig 13: MEK test failed at low PMT in topcoat oven.

5.4.2 Hardness Test

A paint coated sample coil was tested with applying fiber castle pencil 2 H, found paint peel off, shown in figure 10.

5.4.3 Impact Test

The painted coated samples coils were tested for impact test, Fig: 11 shows a coil with heavy disbondment of coating, and Fig; 12 shows resistance of impact.

5.4.4 MEK (Methyl ethyl ketone) Test :

The paint coated sample was tested for MEK test by rubbing cotton wool over sample up to 100 times. Fig: 13 shows paint peel off due to low PMT in top coat oven.

6. Uses of coatings

The most common application of coated steel are cladding, white good sectors, automotive and air space, which is shown in

figure 14.

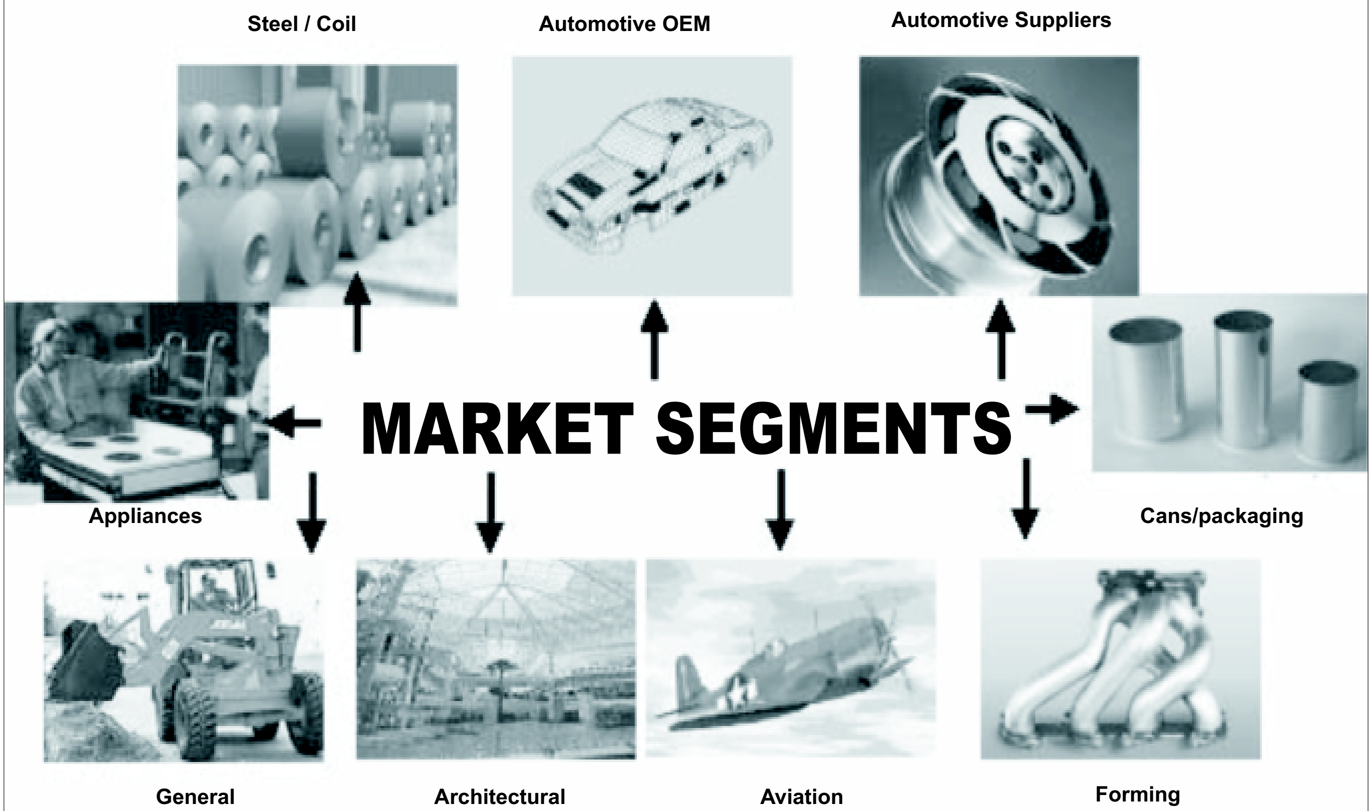

Fig: 14. Market segments for paint coated products

7. Conclusions:

1. The performance of the coil coating line was degraded when the tension values are deviated from optimized range in chemical section, process section and exit section respectively.

2. The coating quality was unacceptable when the concentration in baths of alkali and conversion coating section was maintained below optimized value. Higher concentrations give same cleaning effect, however the production cost increases marginally.

3. The coating defects like crater formation due to hydrogen evolution were not observed after maintaining proper baking in oven.

4. The coating quality passed all necessary tests when the PMT in primer oven and top coat ovens are maintained in the optimized range.

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