Use of High Zinc Bath Entry Strip Temperature to Solve Coating Problems

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(Received July 30, 2009; Revised October 25, 2010; Accepted October 27, 2010)

The auto industry is demanding more ductile high-strength steel grades to build lighter and stronger car bodies. The hot-dip galvanizing problems of these new steel grades are creating a demand for an improved method to control zinc wettability. The simplest way to improve zinc wettability on industrial hot-dip galvanizing lines is to increase the strip immersion temperature at zinc bath entry for enhancing the aluminothermic reaction. However, this practice increases the reactivity due to overheating the zinc in the snout which induces the formation of brittle Fe-Zn compounds at the strip/coating interface with the formation of higher amounts of dross in the zinc bath and snout contamination. Thus, this simple practice can only be utilized for short production periods of one to two hours without deteriorating coating quality. This problem has been solved by employing a technique that allows the use of a higher and attuned strip immersion temperature at zinc bath entry while still maintaining a constantly low zinc bath temperature. This has been proven to provide the solution for both the improved wettability and a significant reduction in the amounts of dross in the zinc bath.

Keywords *: carbide-free bainite, dross management, hot-dip galvanizing, new advanced high-strength steels*

1. Introduction

The operators of galvanizing lines prefer to have only three pot rolls and no other equipment in the zinc bath to minimize the maintenance costs. However this system has many disadvantages including limited options to control the reaction of the IM-layer on the steel strip at 0.2 second of immersion based only on the control of the bath aluminum. There is only a small window during the entire galvanizing process to control the IM-layer via the bath aluminum content within very tight limits to maintain the amount of total coating aluminum as low as possible and still achieve the best surface quality. This window occurs during the first 0.2 second of immersion of the strip into the zinc pot or approximately one meter length of strip. The ability to control the IM-layer is lost when the strip comes into contact with the sink roll and is pressed against the roll surface by the high tension of the strip making it difficult to get a good final coating on the steel strip thereafter. The improper formation of the IM-layer will be a source of transfer of iron into the zinc bath causing a dross problem.

Typically, the coating quality is adversely affected by dross pickup defects. Vortexes created by the moving steel strip and sink rolls facilitate the system for growth of larger dross particles which generally cause dross pickup defects on the strip. Conventional galvanizing offers no solution to eliminate and/or minimize the formation of these vortexes. As a result of the large amounts of dross that is being created using conventional galvanizing, there is a very short production time in which critical surface quality can be achieved to produce premium-coated steel grades. At the same time maintenance costs are increased due to frequent line stops to change the sink rolls because of dross build-up on the rolls, even when using recently developed, sophisticated mechanical scrapers.

The auto industry is demanding more and more ductile high-strength steel grades to build lighter and stronger car bodies. The hot-dip galvanizing problems of these new steel grades are creating a demand for an improved method to control zinc wettability. The simplest way to improve zinc wettability on conventional galvanizing lines is to increase the strip immersion temperature at zinc bath entry for enhancing the aluminothermic reaction. However, this practice increases the reactivity due to overheating the zinc

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in the snout which induces the formation of brittle Fe-Zn compounds at the strip/coating interface and with the formation of dross in the zinc bath and snout contamination. Thus, this simple practice only can be utilized for short production periods of one to two hours without deteriorating coating quality.

This problem has been solved by employing a new technique that allows the use of a higher and attuned strip immersion temperature at zinc bath entry while still maintaining a constantly low zinc bath temperature. This has been proven to provide the solution for both improved zinc wettability and a significant reduction in the amount of dross in the zinc bath. It is well-known that the best way to reduce dross in the zinc bath is to increase the formation kinetics of Fe_2Al_2, which is only possible by lowering the bath temperature if it is not possible to increase the aluminum in the zinc bath.

The new technique will also solve the above mentioned disadvantages of conventional galvanizing including effective management of dross and providing significantly longer time, over two-times than current galvanizing, to produce premium coated steel grades. All of these will result in a significant reduction in maintenance and operation costs, even though it will require additional equipment in the zinc bath.

2. Dross formation related to the dissolved iron from steel strip

The general target for galvanizers is to use equal strip entry and zinc bath temperature. The amount of iron dissolved from the steel strip into the bath is generally assumed to be directly related to the zinc bath temperature,[1] not primarily to the temperature of liquid zinc in the snout at the strip entry area at 0.1 sec of immersion. With conventional galvanizing the temperature of the liquid zinc at strip entry is 465 °C which is approximately 5 °C higher than the temperature measured by a thermocouple in one corner of the zinc pot shown in Fig. 1.

Conventional galvanizing technology will need to use electricity for melting the zinc ingots by full firing the inductors for the zinc pot. As shown in Fig. 2 and Fig. 4, the strip entry temperature over 465 °C will cause a high formation of dross and thus poor coating quality. Also the gas-jet cooling of the steel strip from 520 °C to 465 °C requires a lot of electricity. Totally these both may consume electricity even up to a range of one million US dollars annually. Therefore, it would be highly desirable if these two separate electricity consumptions could be combined to cooperate with each other so that no electricity is wasted. For example, the heat released from the strip could be used in the zinc bath for melting zinc ingots. This is only possible using the new galvanizing technology called ZQ-Dynamic Galvanizing® due to less dross in the zinc pot.

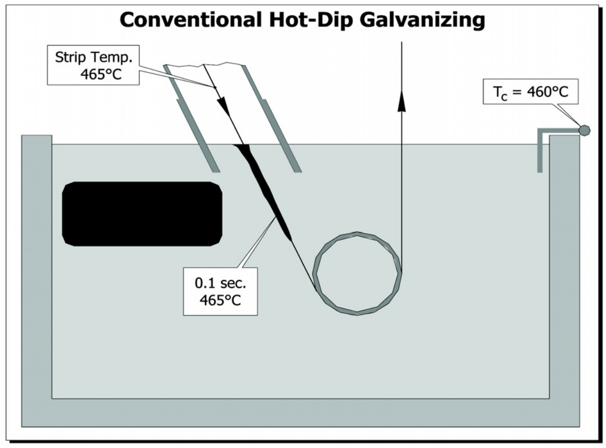


Fig. 1. The dissolution of iron from the strip is directly related to temperature of the liquid zinc around the strip at 0.1 second of immersion. To minimize the dissolution of iron from the strip the temperature of the liquid zinc at 0.1 second should be kept as low as possible.

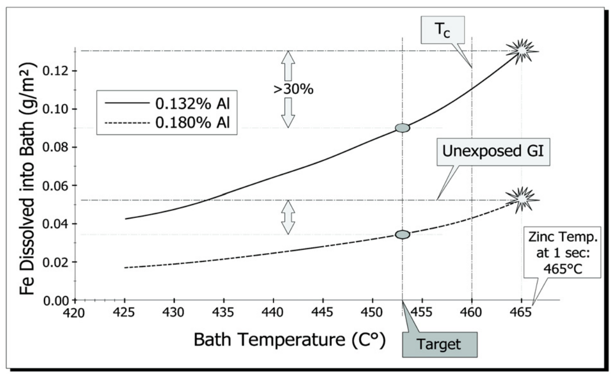


Fig. 2. The dissolution of iron from the strip is directly related to temperature of the liquid zinc around the strip at 0.1 sec of immersion. To minimize the dissolution of iron from the strip the temperature of the liquid zinc at 0.1 second should be kept as low as possible.

3. Growth of dross particles by vortexes

It is well-known that the moving strip driving the sink roll and stabilizer rolls as well as the inductors, if at maximum power, will create vortexes in the zinc bath[2),3),4),5)] which will collect and prevent the tiny dross particles from being removed quickly from the zinc bath causing growth of particles by coalescence, shown in Fig. 3. It is quite impossible to eliminate these vortexes in practice using

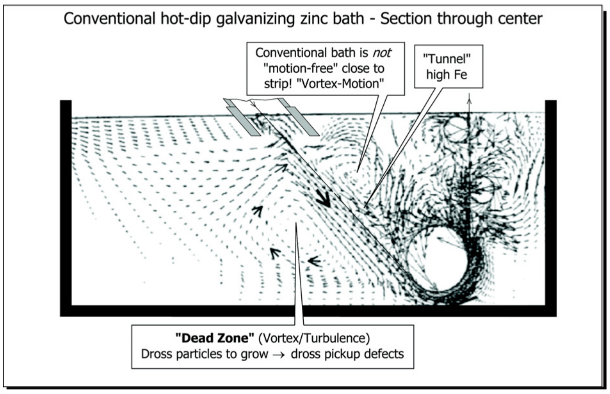


Fig. 3. Vortexes in the zinc bath will enhance tiny dross particles to grow by coalescence over 20 microns and cause dross pickup defects.

conventional technology,[6,7] and thus the problem of iron continuously dissolved from the strip creating an excessive dross issue has not been solved. Conventional hot-dip galvanizing zinc bath-Section through center Conventional bath is not "motion-free" close tostrip! "Vortex-Motion" "Tunnel" highFe "Dead Zone" (Vortex/Turbulence) Dross particles to grow dross pickup defects

4. High strip entry temperature-aluminothermic reaction

It is also well-known[8] that the use of a higher strip entry temperature will solve many galvanizing problems due to limited coatability or wetting issues because steel grades like HSLA-grades and new AHSS-grades have difficult steel chemistries with high amounts of Mn-alloy and sometimes high Si-% (>0.20%) and boron. However, this is only applicable for limited operating periods of one to two hours, i.e. producing two to four coils. Thereafter the coating quality will deteriorate, and the formation of dross in the zinc bath will be increased beyond the respectable limit of a conventional galvanizing practice. The reason is illustrated in Fig. 4 which shows that the high strip-T will increase the liquid zinc temperature at 0.1 sec and reaction temperature at 0.2 sec will become too high.

A higher strip entry temperature will enhance the activation energy for aluminothermic reactions using aluminum in the zinc bath as the reducing agent for Mn-, Si-, Cr-, etc., oxides on the strip surface. Aluminothermic reactions are exothermic and thus a high activation energy is needed to start them.

Limitations of the conventional method for successful aluminothermic reactions are:

- Overheating the liquid zinc in the snout; limited operation time and poor coating quality.

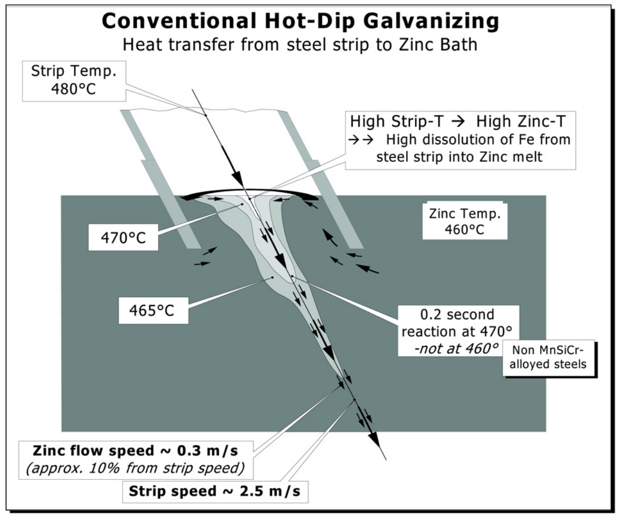


Fig. 4. The high strip entry temperature will overheat the liquid zinc around the strip at 0.1 sec immersion enhancing the dissolution of iron from strip and formation of dross especially in the snout. This will limit the use of high strip entry temperature only to be used temporarily.

- No removal of the reaction products by zinc flow from strip surface will stop the reaction.[9]
- Significant local consumption of aluminum when galvanizing high Mn-alloyed steels which would result in located depletion of dissolved bath Al at the bath/substrate interface, promoting inhibition breakdown.[10]

$$3MnO(s) + 2Al(bath) \leftrightarrow 3Mn(bath) + Al_2O_3(s)$$

Only thin MnO-layer will be reduced by aluminothermic reaction using the conventional process from the strip surface for metallic Fe to react to bath-Al.[11]

$$Fe_{(strip)} + 3Al_{(bath)} \rightarrow FeAl_{3(strip)}$$

5. New technology-continuously dross-free zinc bath

It should be a great benefit of the galvanizing operation to have a simple and consistent technology to use any strip entry temperature continuously for difficult steel chemistries and still keep the zinc bath temperature at 0.1 sec consistently low and the general bath temperature variation less than ± 0.5 °C regardless of the strip entry temperatures. ZQ-Dynamic Galvanizing® will provide this solution. The flow pattern of ZQ-DG shown in Fig. 5 provides a unique purification of the whole zinc melt four to six times per hour. There are no vortexes as in conven-

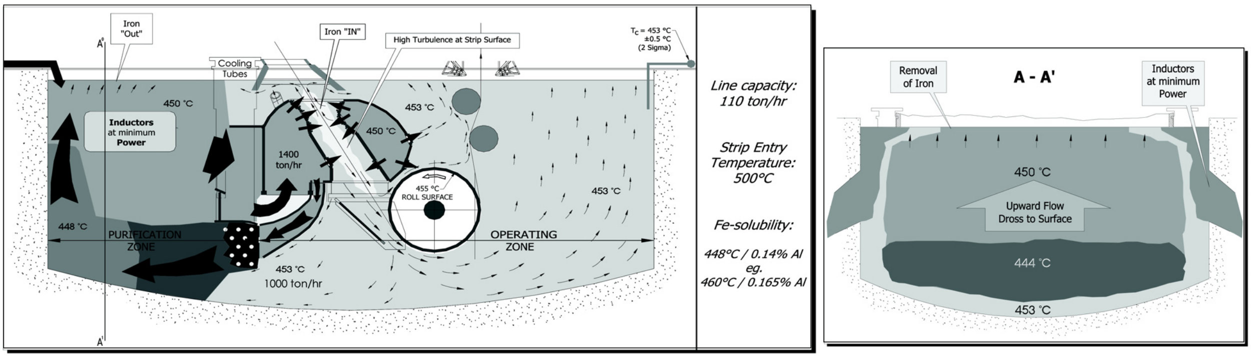
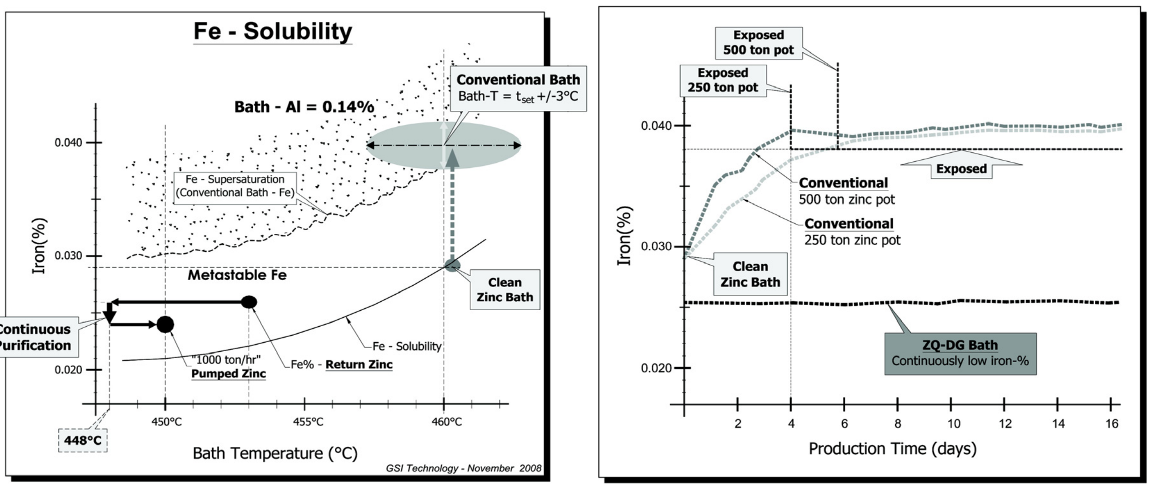


Fig. 5. ZQ-DG will transport continuously 1,000 ton/hr zinc from Operating Zone through Purification Zone where the major portion of the dissolved metastable iron from strip will be floated into Top Dross for removal.
Purification is based on the driving forces of the low bath temperature and higher aluminum content to precipitate metastable iron from the zinc melt when the zinc is pumped against the back wall of the zinc pot.



(a) (b)

Fig. 6. (a) The solubility of iron in the zinc melt with 0.14% aluminum is shown as the function of the zinc bath temperature. The low iron content of a ZQ-Dynamic Galvanizing® zinc bath will indicate a virtually dross-free zinc melt. (b) To produce high quality zinc-coated surface products, the zinc bath iron content should be below supersaturation. ZQ-DG can provide a continuous low iron content in the zinc bath which is opposite of conventional technology.

tional galvanizing which provides a long dwelling time of tiny Fe-Zn-crystals, one micron,[12] to grow into large dross particles in the zinc bath. Thus the zinc bath can be kept virtually dross-free as indicated by a very low Fe-content in the bath shown in Fig. 6(a). Dross-free/clean zinc is only Fe-Zn-Al-crystals with two to five microns or less than 10 microns. Dross particles over 20 microns should be continuously purified and floated to the top surface of the zinc melt for removal.

ZQ-DG Technology can significantly reduce the amount of Fe dissolved from the strip because (a) the zinc melt pumped against the immersing strip is much colder than 460 °C, the conventional bath temperature; and as a result, the driving force for the formation of inhibition compounds, not only the necessary Fe_2Al_5, is greatly increased; and (b) the kinetics is much higher. This again reduces Fe dissolution from the strip. The bath is indeed cleaner in ZQ-DG.[13]

6. Enhancement of the aluminothermic reaction by new technology

ZQ-Dynamic Galvanizing® allows the use of a continuously high strip entry temperature without overheating the liquid zinc in the snout. The strip temperature can be attuned to be optimum with respect to the coating quality, mechanical properties of the steel and minimum formation of dross in the zinc bath.

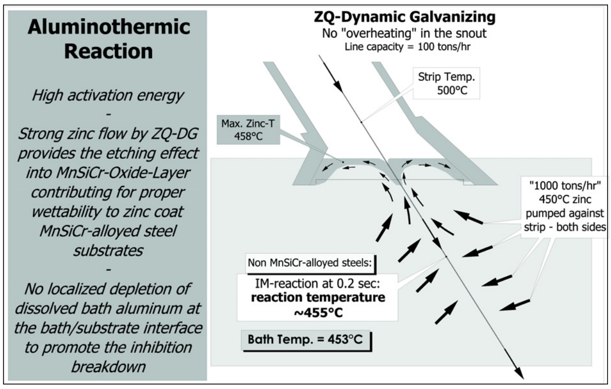


Fig. 7. It is important to note that the reaction temperature at 0.2 sec is constant due to the amount of cooler purified zinc pumped consistently against the strip in order to continuously flush the snout.

7. Industrial operating results of new technology

The benefits of ZQ-DG for traditional grades are reported by Ispat Inland, Inc. from their #5 CGL:

a) 11.5 days to 21 days with one sink roll, welded Stellite built bearings and sleeves.
b) 12,000 more production capacity.
c) Less rejections.
d) Longer campaigns for high Mn-alloyed HSLA-grades, etc.

These benefits[14] are from the ZQ-DG generation used in 2004 having direct suction of zinc melt through the cooling tube bundle into the inpot unit. The latest development of ZQ-DG Technology is implementing reverse Al-fresh zinc flow through the cooling tube bundle which will eliminate any precipitation of metastable iron in the zinc melt during cooling. The formed dross particles will be pumped into the Operating Zone from Purification, if some dross precipitations will occur around the cooling tubes. These two flow patterns are shown in Fig. 8.

8. Accumulation of dross in snout - conventional

The snout in conventional galvanizing will be contaminated by dross emerging from the dead zone above the sink roll "V". This emerging zinc from the front will also flow behind the strip in the snout. This has been modeled by Nisshin Steel[15] and shown in Fig. 9.

9. Recent snout technology to avoid dross - conventional

Currently many galvanizers who are producing exposed surface quality are using a snout with dams and metal pumps that continuously remove zinc from the snout[16] in an attempt to remove the large amounts of dross infesting the snout. One of the biggest problems with this solution is the huge vaporization of zinc creating a zinc dust problem in the chute as illustrated in Fig. 10. There is also

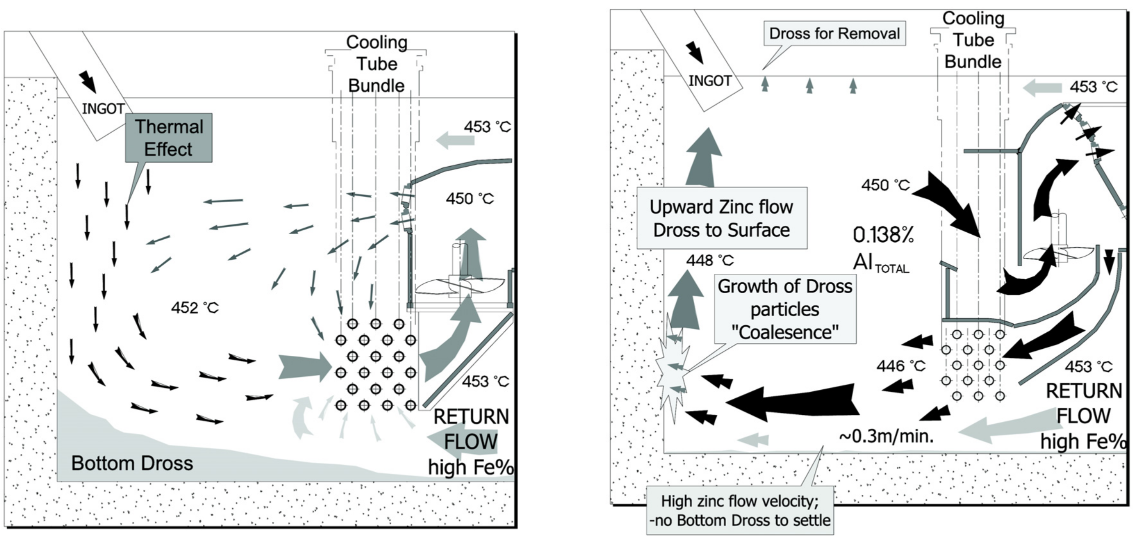


Fig. 8. Comparison of the flow patterns in the Purification Zone; (a) is the original concept used in 2004; and, (b) is the new concept with the upward flow in Purification Zone to float tiny dross particles into Top Dross removal. Note: Suction is turbulence-free. Blowing creates turbulence against the pot wall as required for coalescence.

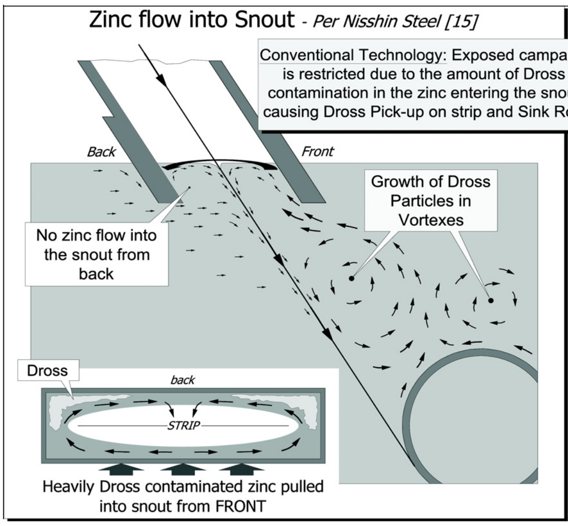


Fig. 9. Conventional-Dross will float into the snout from the V-zone above the sink roll due to the flow pattern created by the moving strip. Inside the snout at the surface of zinc melt the floating dross will slowly accumulate, and the strip will pickup dross particles creating coating defects.

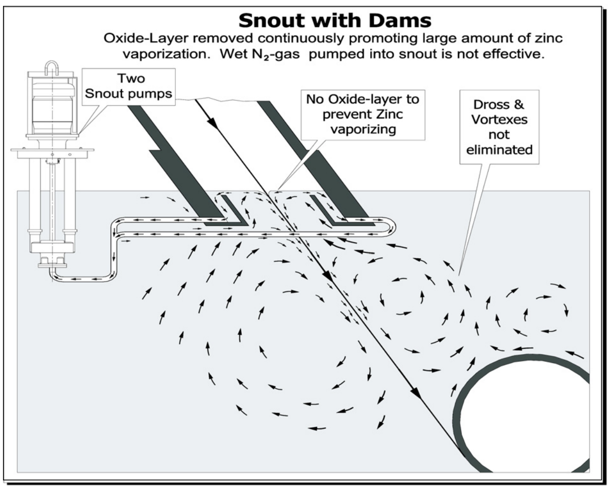


Fig. 10. Snouts with dams and metal pumps will undesirably pull the seal of the oxide-layer/skin from the zinc surface inside the snout. Thus, the amount of zinc vaporizing is difficult to minimize even when using wet nitrogen inside the snout.

a maintenance problem because the snout pumps have a short lifetime from three to eight weeks due to hard erosive dross particles in the zinc melt that is pulled from the snout.

10. Reverse flow of dross-free zinc into snout by new technology

ZQ-DG will continuously pump dross-free/low Fe-content, Al-fresh zinc melt against the strip and into the snout, and the zinc is continuously discharged from both ends of the snout as shown in Fig. 11. This will eliminate the dross contamination in the snout which is a problem with conventional galvanizing technology. The high volume of dross-free/low Fe-content zinc that is pumped by ZQ-DG will provide unique benefits that are impossible to achieve using conventional galvanizing technology to avoid the formation of metastable BCC Fe(Al)-phases with 0.14% bath-Al. To consistently produce high-quality hot-dip zinc-coated products, a dross-free/clean snout is the most important requirement.

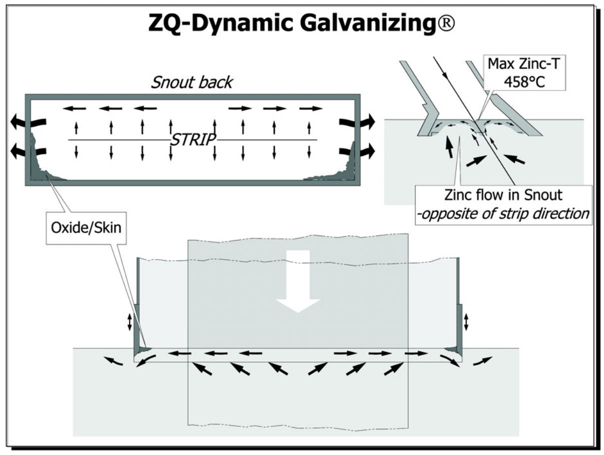


Fig. 11. ZQ-Dynamic Galvanizing® will constantly pump dross-free/low Fe-content zinc melt into the snout, and zinc is continuously discharged from both ends of the snout.
ZQ-DG keeps the zinc melt in the snout at low Fe-content level (<0.026%) even with 0.14% bath-Al. Thus, the formation of metastable BCC Fe(Al)-phases will be avoided at 0.2 sec of immersion, opposite conventional galvanizing, which easily has more than 0.05% Fe-content in the zinc melt at the 0.2 sec reaction location. The high Fe-content is the driving force for the formation of BCC Fe(Al)-phases[13)] and there is always a time delay to form optimum IM-layer beyond the sink roll.

11. Model-how iron is transferred from strip into zinc bath

H. Yamaguchi and Y. Hisamatsu in 1978 presented the mechanism[17)] for how iron is transferred from the steel strip into the zinc bath mainly above and after the sink roll. It is extremely important that the IM-reaction at 0.2 to 0.5 sec of immersion will form a compact, thin, uniform layer with 100% coverage without loose Fe-Zn-Al crystals on top at this IM-layer, which could easily be pulled out from the IM-layer mainly from the sink roll. The loose particles on the IM-layer will enhance dross formation in the zinc bath and dross buildup on the sink roll as shown in Fig. 12(a). The upper/diffusion layer is loosely attached to the lower/reaction layer.[18] Therefore, the crystals of this layer can be easily pulled off into the zinc melt above the sink roll. Due to the strong vortexes these tiny crystals will grow by coalescence to big dross particles in the dead zones, and the strip will pick them up onto the coating creating dross defects. Also, the ends of the sink roll will create very strong tornadoes circulating dross up from the bottom of the zinc pot as shown in Fig. 12(b).

12. Prevention of dross circulation around the sink roll

The production time per sink roll will be significantly

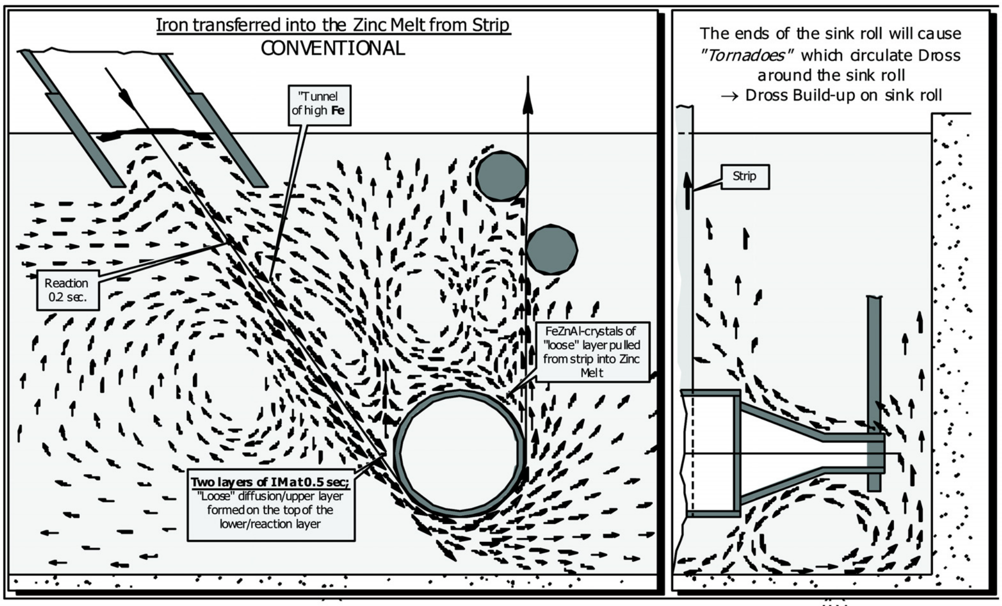


Fig. 12. (a) Strip will pull dross particles onto the surface before the sink roll enhancing the formation of loose upper layer which will enhance iron dissolution from the strip into zinc. (b) Ends of the sink roll will lift the dross and prevent dross particles from settling on the bottom of the zinc pot.

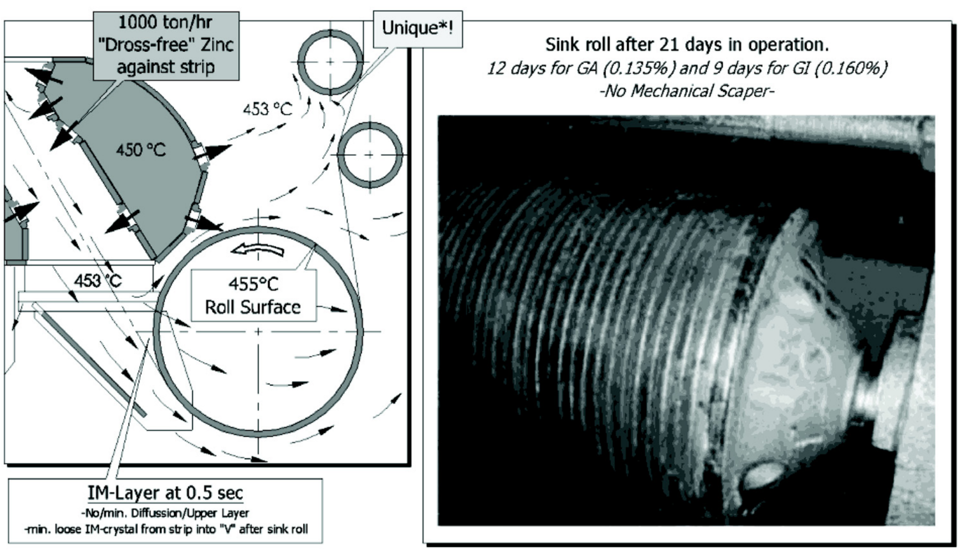


Fig. 13. ZQ-Dynamic Galvanizing® will prevent the circulation of dross around the sink roll. It is possible to keep the roll surface clean from dross build-up over three weeks without a mechanical scraper even with low bath aluminum content used for GA-coating.

increased continuously providing clean sink rolls by ZQ-DG as shown in Fig. 13. The recent study[19] has shown that the material choice for the sink roll will not solve the problem of dross buildup on the sink roll which is solely dependent on Hydrodynamics around the sink roll. ZQ-DG will provide the optimum hydrodynamic conditions as shown in Fig. 13 by continuously flushing dross-free zinc around the sink roll, and no vortexes/dead zones with dross accumulation above the sink roll are possible. The unique direction of the upper flow nozzles will minimize the pickup of top dross onto the steel strip without baffles as suggested by S.J. Lee, et. al.[20]

13. Gi and ga in one zinc pot-conventional vs. new technology

Virtually one bath aluminum content[21] of the new technique for GA and GI improves the productivity of the line to produce GA and GI with the highest flexibility without troublesome bath Al transitions and bath cleaning from dross after GA campaigns which is required by conventional galvanizing.[22] Fig. 14 illustrates the bath-Al practices for conventional and ZQ-DG. During this bath cleaning the produced product quality is downgraded and/or produced steel coils sold without profits or even losses if only one pot is used for both GI and GA. During

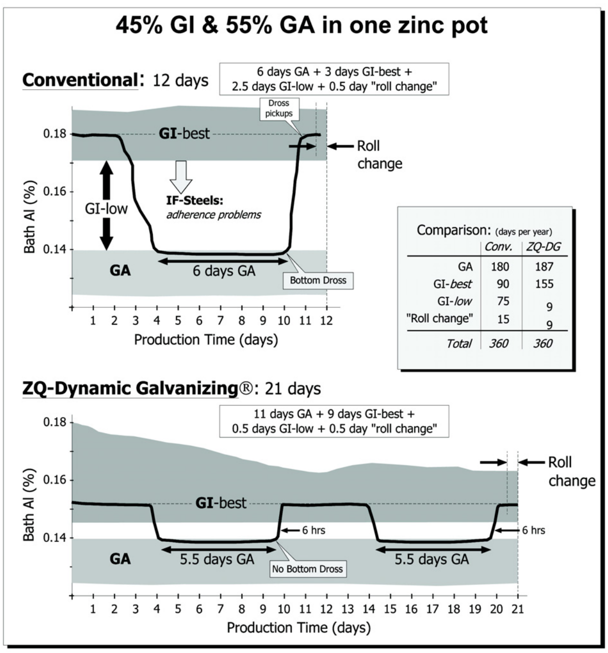


Fig. 14. Using virtually one bath aluminum content for GA and GI improves the productivity of the line to produce premium grades with the highest flexibility without troublesome bath Al transitions and cleaning of dross after GA campaigns which is required by conventional galvanizing.

the transition from GA to GI, the bottom dross is converted by the increased bath-Al to floating dross[23] causing significant dross pickup defects on the strip:

$$2FeZn_7 \text{ (bottom dross)} + 5\ Al \rightarrow 14\ Zn + Fe_2Al_5 \text{ (floating dross)}^{23)}$$

Also during the transition from GI to GA, it is not possible to produce IF-steels by conventional galvanizing due to reduced bath aluminum below 0.17% when the adherence of coating for IF-steels is desirable/good. ZQ-DG has continuously produced a good GI-coating quality for IF-steels even with bath-Al = 0.145% with no outbursts.

14. Optimization of im-layer to obtain compact ga-coating

The combination of the high strip entry temperature and

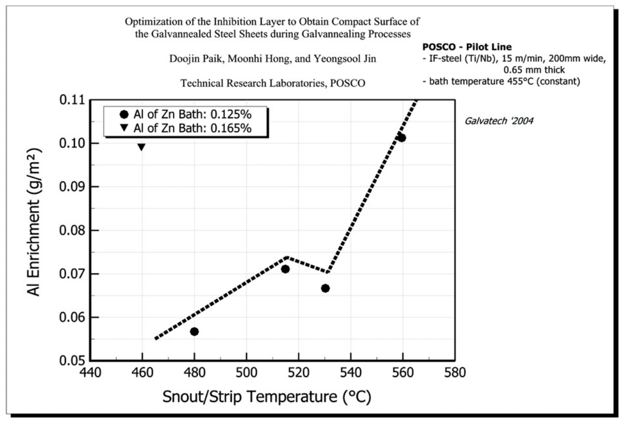


Fig. 15. Al enrichment as the function of strip entry temperature.

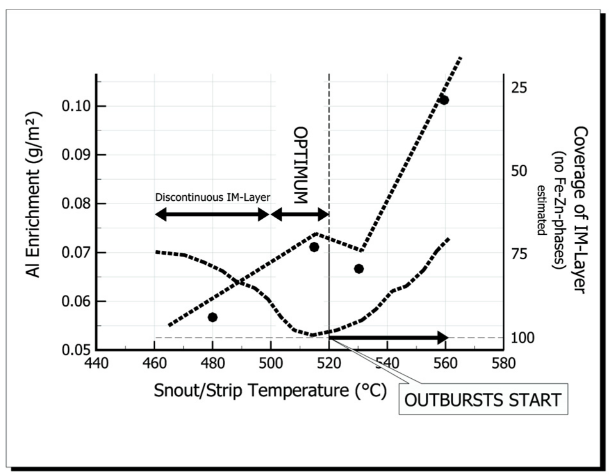


Fig. 16. Optimum strip entry temp. based on the results shown in Fig. 1 - to achieve full coverage of IM-layer during the dipping of strip into zinc bath in order to produce good GA-coating for stamping.

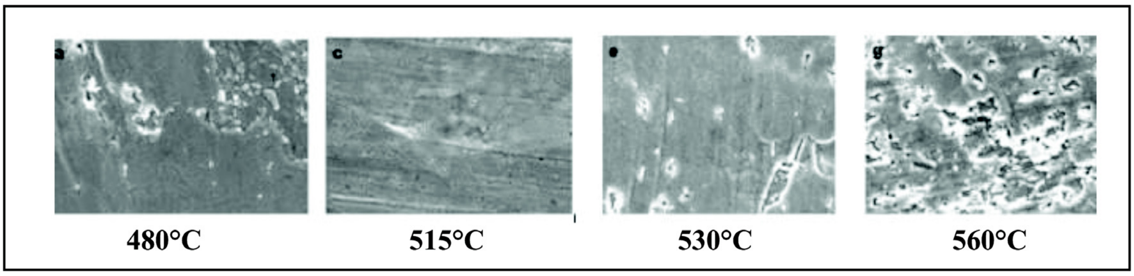


Fig. 17. FE-SEM images of the inhibition layers formed at different snout/strip temperatures. The zinc bath temperature is kept constant at 455 °C. Snout/Strip temperature: 480 °C-discontinuous IM-layer with holes/spots of zeta-phase; 515 °C-optimum, fine-grained, compact thin IM layer; 530 °C-some outburst; 560 °C-a lot of outburst.

low bath temperature with low bath-Al for GA has been proven to provide the optimum combination[24] to control the formation of IM-layer as shown in Fig. 15 based on the results shown in Fig. 16. ZQ-DG provides these equal conditions consistently in the industrial scale line of 100 tons/hr. The full coverage of IM-layer before wiping zinc off by the gas knives is important to achieve a GA-coating with minimum powdering and Zeta-phase content for good stamping performance.

15. Thermal cycles to produce new ahss-grades

With the new AHSS-grades, the cooling path after the intercritical annealing will play an important role regarding how much the steel chemistry needs to be alloyed to produce the desired mechanical properties. Conventional galvanizing will need to be over 0.15% alloying of Mo.[25]

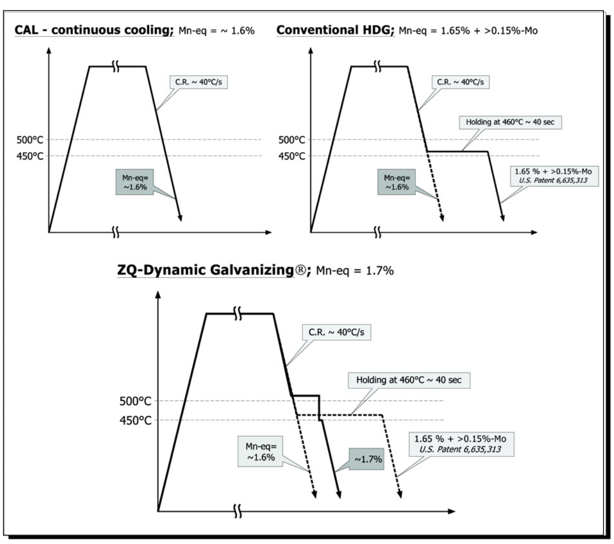


Fig. 18. Comparison of different thermal cycles to produce DP-600 grades. CAL will produce uncoated steel strip. [Mn-eq = Mn-% + Cr-% + 0.3Si-%]

16. Formation of cementite carbides not desirable for ahss-grades

The formation of cementite carbides is kinetically highest at the temperature range of 450-500 °C shown in Fig. 19.[26] This temperature range is unfortunately where the equalization of the steel strip will be carried out after the rapid gas-jet cooling before the zinc bath using the conventional hot-dip galvanizing method. The cementite carbides together with bainitic ferrite will form the structure of the upper bainite. Pearlite is similar to upper bainite, and both are not desirable for dual phase steels. Cementite carbides, i.e., upper bainite, is formed at holding temperatures below 500 °C. Cementite carbides are a waste of carbon because all available carbon in the steel should be used for the formation of martensite.

The short holding above 520 °C is the best temperature range for hot-dip galvanizing due to the necessary stop of rapid cooling because of the zinc bath after the rapid gas-jet cooling at the hot bridle and chute/snout region.

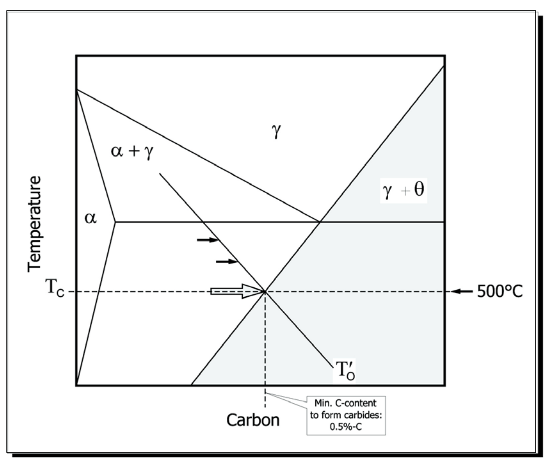


Fig. 19. Holding below 500 °C should be avoided to prevent the formation of cementite carbides, i.e. upper bainite, because all the available carbon in the steel should be used for the formation of martensite.

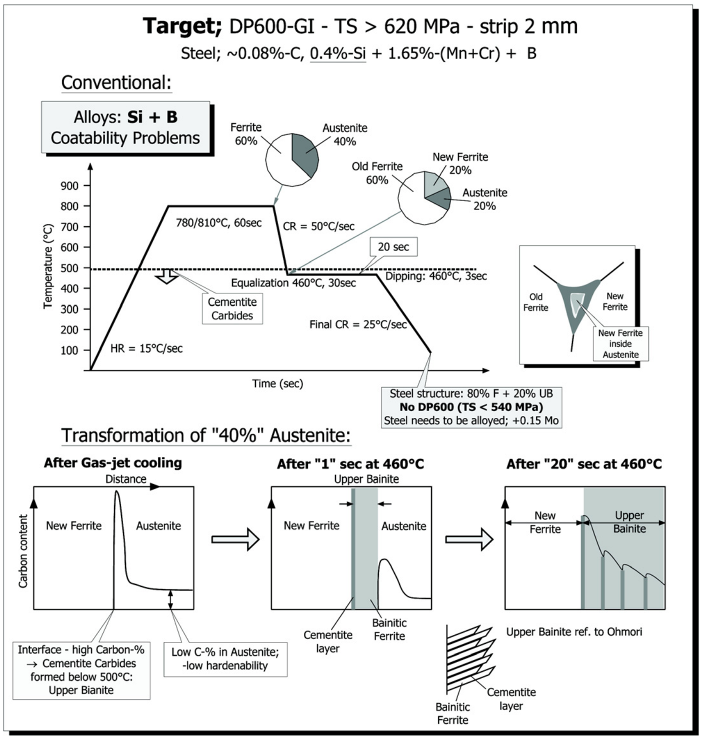


Fig. 20. Conventional-long holding at 460 °C before zinc bath will require the use of high-alloyed steel chemistries with Mo-alloying to produce DP600-GI and to avoid the formation of Upper Bainite. Coatability problems will restrict the use of low-cost alloying elements such as Si and B.

17. DP600-GI by conventional

To economically produce dual phase steel structure of ferrite and martensite for good spot welding properties the steel chemistry should have carbon content of less than 0.10%, preferably only 0.08%, and manganese less than 1.7% without Mo-alloying. This is really challenging or impossible with conventional galvanizing technology as shown in Fig. 20. The main reason is because with the thermal cycle of conventional galvanizing the holding or equalization is at 460 °C/470 °C after the rapid gas-jet cooling before the zinc bath. The formation of cementite carbides, i.e. Upper Bainite by Ohmori[27] below 500 °C is difficult to avoid if the dwelling/holding time of the strip at 460 °C is more than five seconds. Therefore, the bainite start-nose must be moved to the right by using expensive Mo-alloying. The high alloying costs will make the profitability of producing the new AHSS-grades very marginal or even create losses instead of producing traditional steel grades.

18. DP600-GI by new technology

Silicon has been known to improve the ductility of DP-steel.[28] The optimum amount of Si is 0.4% for GI-coated DP-grades. However, if Si is more than 0.2% then conventional galvanizing[29] has coatability problems without DFF-preheating furnace and even sometimes with this furnace. Another desirable alloying element is boron which 30 to 40 ppm is needed to produce a high hardenability for steel above 540 °C which actually will eliminate the formation of pearlite even with lean-alloyed Mn-Si chemistries. Also coatability problems are significant due to B-alloyed steels by conventional galvanizing. The high strip entry temperature of ZQ-DG will solve these coatability difficulties of Si- and B-alloyed steel chemistries making it possible to economically produce DP600-GI grades as shown in Fig. 21. The kinetics of bainite formation is significantly reduced above 500 °C compared to 460 °C.[30]

19. Summary

Benefits of the new galvanizing technique over the conventional/current galvanizing technique:

1) Effective management of dross to minimize dross pick-up defects on coating based on the following two issues:

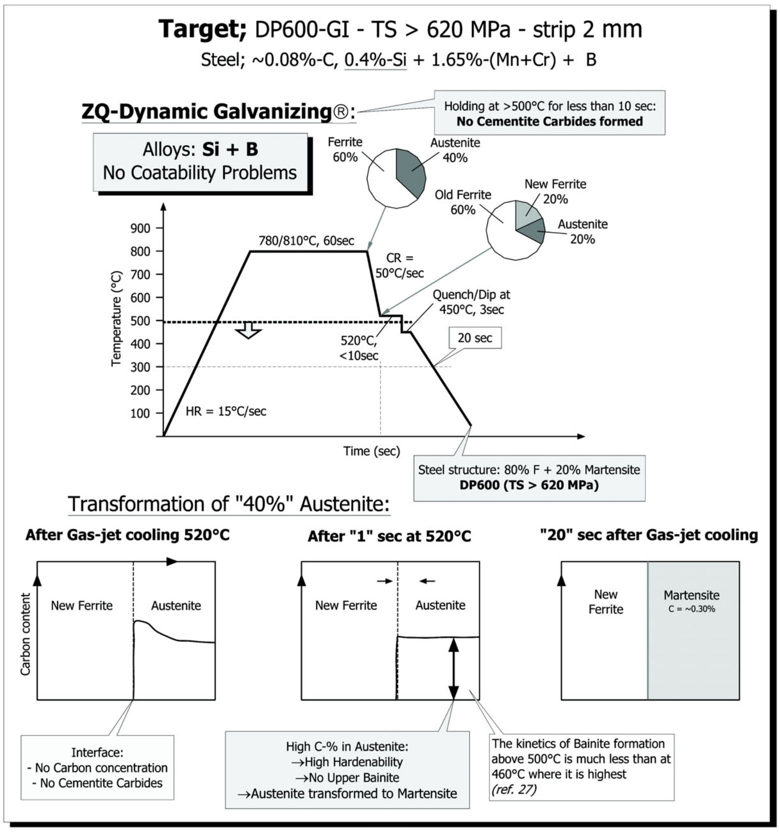


Fig. 21. ZQ-DG makes it possible to use Si- and B-alloyed steel chemistries to economically produce DP600-GI steel grades.

ⓐ To minimize the amount of iron dissolution from steel strip into zinc bath; and,

ⓑ To continuously purify zinc melt using a low bath temperature in the back bath zone with a unique upward zinc flow to float tiny Fe-Zn-Al-crystals continuously to the zinc bath surface for removal as top skimmings. This is impossible using only aluminum to float dross.

2) Significantly longer production time for premium coated steel grades with a consistently dross-free zinc bath indicated by low iron content in the zinc melt and also above the sink roll.

3) Improved control of zinc wetting by use of a high zinc bath entry strip temperature to enhance the aluminothermic reduction reaction for steel substrates of Mn-Si-Cr-alloyed steel chemistries.

4) Significant operation and maintenance cost savings due to less scheduled line stops for pot roll changes. Additionally, significant electricity savings can be achieved utilizing the heat of the strip to melt zinc ingots and less electricity used for strip cooling before the zinc bath.

5) Economical and flexible production of GI and GA in one zinc pot without long bath aluminum transition periods and cleaning of dross from the zinc bath as is required in conventional galvanizing.

6) DP/AHSS-grades can be produced much more economically from lean Mn-Si-alloyed steel chemistries than by conventional galvanizing which needs to use high-cost Mo-alloying in steel chemistries.

7) Important enhanced capability to produce ultra high-strength steel grades which will be demanded more and more from the auto industry in the future.

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