Cost Effectiveness Study of a Novel Hot-dip Galvanizing Process

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Abstract

A novel hot-dip galvanizing process for steel has been developed to improve the longevity of the finished product and reduce zinc layer thickness. Its cost effectiveness, however, has not been validated. This paper studies the cost differences between the novel and the traditional processes by constructing a process-based cost model and using it to investigate important process cost drivers. Sensitivity analyses on the drivers provide product and process characteristics which will guarantee the cost effectiveness of the technique.

***Keywords**:* Galvanizing, Cost effectiveness, Cost modeling

1. Introduction

Hot-dip galvanizing is a process whereby zinc is applied on a steel surface to prevent it from corrosion. Galvanized steels find many uses ranging from construction to industry to agriculture due to short processing time, durability, and ease of maintenance [1].

The intermediate coating layer of Fe-Zn phase formed upon the conventional hot-dip process is beneficial to the longevity of the coating. By prolonging the immersion duration of a steel article in a molten zinc bath, the thickness of the coating layer is increased. Due to the layer's brittleness, however, excessive thickness is undesirable [2, 3]. Furthermore, excessive thickness implies uneconomical use of zinc, leading to unnecessarily costly products.

R. Sa-gnuanmoo et al. [4] has discovered that introducing a nickel layer of controlled thickness, either by electrodeposition (electroplate) or electroless-deposition (electroless), to steel before hot-dipping can suppress the growth of the intermediate layer, The intermediate coating layer of Ni-Zn formed through this process is also shown to provide considerable enhancement of corrosion resistance to the coating [4]. However, the novel galvanizing process is different from the traditional one in several ways, including the addition of the nickel plating step and the reduction of zinc consumption, all of which could affect to the final production cost. To justify the economic feasibility of the novel galvanizing process, therefore, the cost effectiveness of the process must be verified.

To achieve that goal, a method to fairly and systematically evaluate the cost of the traditional and novel techniques must be established. Furthermore, the method should be sufficiently flexible so that it can assess the effect of variations in manufacturing parameters on cost. Process-based cost modeling (PBCM) is a method that integrates operational requirements with physical relationships to evaluate the financial impact on a manufacturing process. It has been widely used to verify cost effectiveness of various manufacturing strategies and processes [5-8].

2. Methodology

2.1 Overview of galvanizing techniques

The galvanizing process can be broken into steps as follow:

1. Acid/alkaline/water bath
2. Flux dip
3. Nickel plate (electroplate or electroless)
4. Oven
5. Zinc hot-dip
6. Rinse
7. Inspection

For the *traditional* technique, the process consists of steps 1, 2, 4, 5, 6, and 7, while the novel technique consists of 1, 3, 5, 6, and 7. For the novel technique, in step 3, nickel plating can be processed using electrodeposition (electroplating)—which relies on external source for electricity—or electroless deposition—which relies purely on electrochemical reactions in plating bath. Galvanizing technique involving electroplated nickel will from this point on be referred to as the *electroplate* technique, and the technique involving electroless nickel plating will be referred to as the *electroless* technique.

Part characteristics such as the thickness of zinc layer and thickness of nickel layer all drive operating parameters like immersion time and electroplating time, which in turns drive the galvanizing costs. And to compare the traditional, electroplate, and electroless technique costs under varying part and process parameters, process-based cost modeling will be used.

2.2 Quantitative methods to evaluate effects of part and process parameters on costs: Process-based cost modeling

Process-based cost modeling (PBCM) is a cost estimation tool that uses part and process characteristics to project manufacturing costs. It is constructed by working backwards from cost, which is the model's objective, to part and process parameters, which are the model's inputs, as illustrated in Fig. 1. The modeling of cost involves (1) correlating the effects of physical parameters to attributes of a process, (2) relating these processing attributes to manufacturing resource requirements, (3) translating these requirements to a specific cost [9].

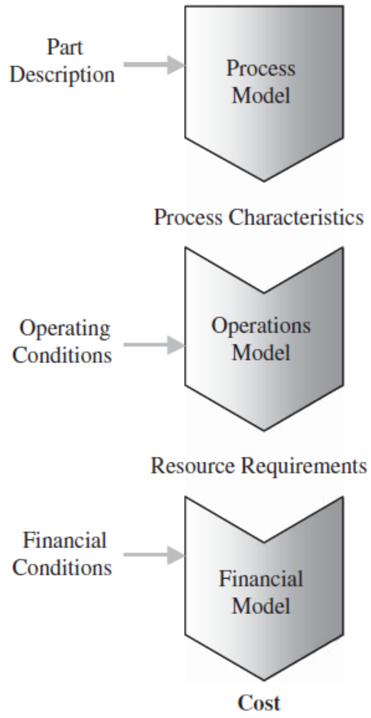

Fig. 1 Schematic of process-based cost modeling

In galvanizing PBCM, the inputs are, for example, part surface area, annual production volume, and required zinc thickness. These would be first used to calculate the immersion duration in a zinc bath. The immersion time and annual production volume would translate to size of bath and number of baths. The size and number of baths will then translate to the investment on zinc baths. Other costs can be calculated in similar ways.

3. Cost Effectiveness Case Studies

To verify the cost effectiveness of the novel technique, the total cost of manufacturing galvanized products using each method needs to be calculated. Furthermore, due to industry practice, costs of galvanization per weight of steel part are also calculated.

To understand the sensitivity of galvanizing cost to various operating parameters, and for ease of comparison, this work will introduce baseline assumptions upon which all other cases will be based. We will assume that

- steel parts considered are a solid cylindrical tube with 9.66 cm diameter and 1 m length, and a hollow tube of same outer diameter and length with 4 mm wall thickness.
- traditional method requires 38 micron intermediate layer, while novel method requires 10 micron. The top pure zinc layer is 25 micron for both methods.
- required nickel thickness is 4 micron.
- zinc hot-dipping duration is 3 minutes.
- annual production volume is 50000.
- turnover life for electroplate solution is 100 cycles, for electroless solution is 10 cycles.
- each of flux bath, acid/alkaline bath, or electroless bath is 50000 baht.
- electroplate machine and bath combined are 100,000 baht.
- bath sizes are the same: 2 x 1 x 1 m
- considering part size and bath size, 10 parts can be dipped simultaneously in one cycle.
- prices of chemicals and metals are shown in Table 1.

Table 1 Prices of chemicals and metals used in galvanizing

Metals and Chemicals	Price in baht per kg (unless noted)
Zinc	91
Lead	40
Aluminium	80

$NiSO_4$	295
$NaPO_2H_2 \cdot H_2O$	250
HCl	2.75 (per liter)
NaOH	18
H_3BO_3	65

- costs of water treatment, ventilation, electronics, and structural equipments are omitted.

3.1 Sensitivity to surface area

The total cost and cost per kilogram are both increasing with part surface area as shown in Fig. 2; since the zinc and nickel thicknesses are kept constant, the total amount of both metals used is increasing.

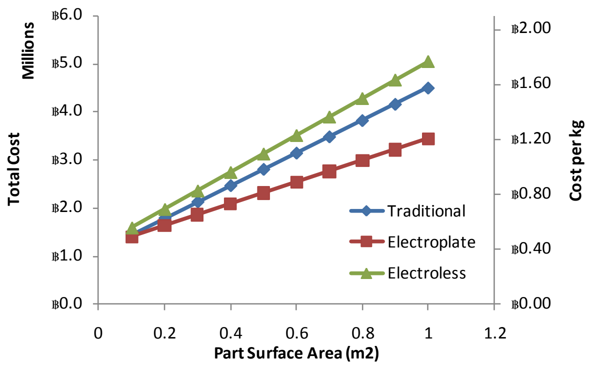

Fig. 2 Total cost and cost per mass of different galvanizing techniques under varying part surface area

Electroplate is the least costly technique across the different areas because it requires smaller zinc thickness than the traditional technique and the duration of electroplating step is shorter than the electroless step.

3.2 Sensitivity to zinc price

As zinc price increases, the galvanizing cost increases regardless of technique, as shown in Fig. 3. Electroplate is still the least costly technique due to the reduction of zinc consumption and fast electroplating step.

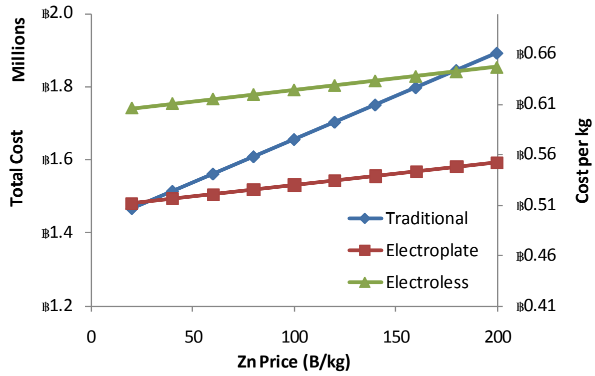

Fig. 3: Total cost and cost per mass of different galvanizing techniques under varying zinc price

Traditional technique is the second least costly because of the combination of costs of flux dipping and oven steps is still less expensive than the electroless nickel plating step. Note also that the slopes of electroplate and electroless diagrams are identical because of the same requirement for zinc thickness.

3.3 Sensitivity to nickel thickness

The electroplate technique is the least costly at less than 5-micron thickness, after which the traditional one is the least costly, as shown in Fig. 4. The electroless crossover point with the traditional technique is at 3 microns.

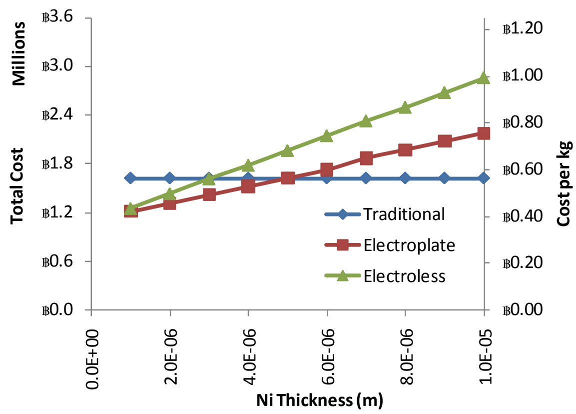

Fig. 4 Total cost and cost per mass of different galvanizing techniques under varying nickel layer thickness

Electroplate and electroless technique costs are very close at small nickel thickness, but grow apart as the thickness increases due to the economy of electrolessly-deposited nickel being worse than that of electroplated nickel.

Note that the traditional technique is insensitive to nickel thickness since it does not require a nickel plating step. As the required nickel thickness increases, so are the costs of electroplate and electroless techniques.

3.4 Sensitivity to annual production volume

As expected, the total cost increases with annual production volume. The slope of each curve indicates the cost per part, showing that the electroplate technique cost per part is the smallest, as illustrated in Fig. 5.

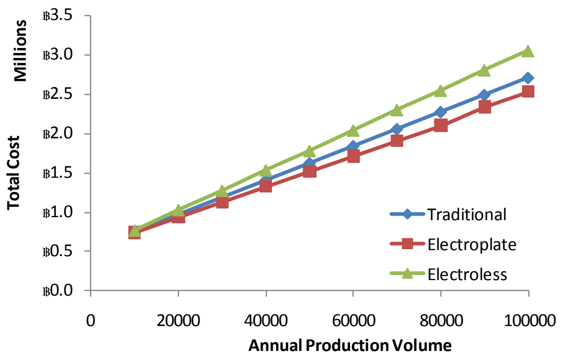

Fig. 5 Total cost of different galvanizing techniques under varying annual production volume

Fig. 6 shows that the cost-per-kilogram curves are decreasing as annual production volume increases due to economy of scale. Again, the cost per kilogram of electroplate technique is the least expensive.

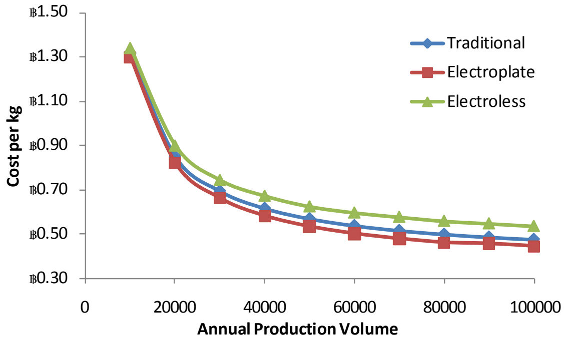

Fig. 6 Cost per mass of different galvanizing techniques under varying zinc price

3.5 Cost by part type

The two types of parts compared are a solid cylinder and a hollow cylinder (tube). The two have the same outer diameter and length, only the tube has the wall thickness of 4 mm. Fig. 7 shows that because the tube has more surface area than the solid cylinder, the total galvanizing cost is higher than that of solid cylinder.

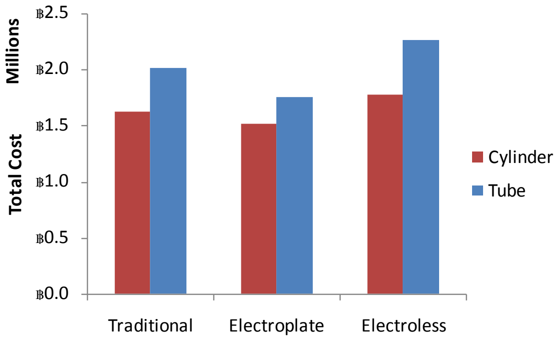

Fig. 7 Total cost of different galvanizing techniques for cylinder and tube parts

The difference is even more pronounced in cost per mass diagram since the surface area per mass of the tube is much higher than the solid cylinder, as shown in Fig. 8.

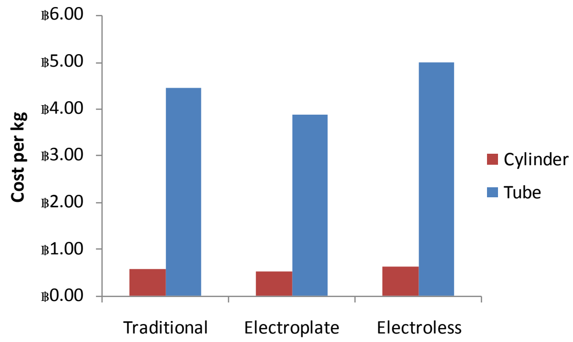

Fig. 8 Cost per mass of different galvanizing techniques for cylinder and tube parts

Regardless of part types, the least expensive technique, both in total cost and cost per kilogram, is still the electroplate technique.

4. Cost Effectiveness Discussion

For the most part, the electroplate technique has been shown to be the least costly both on a total and a per kilogram bases due to thinner zinc layer, relatively short nickel plating time, and low thermal energy consumption. This is true except where the nickel thickness required is larger than 5 micron.

The electroless technique proves to be more costly than the traditional one due to high turnover rate for plating bath (every 10 cycles, as opposed to 100 for electroplate), high thermal energy consumption, and long plating cycle time. Unless nickel and zinc prices are very low, the traditional technique is the less costly.

5. Conclusion and Future Opportunities

The sensitivity analyses show that the novel electroplate-galvanizing is the least costly technique in all situations, as long as the required nickel thickness is below 5 microns. This new technique could therefore allow the production of galvanized steels of improved corrosion resistance at reduced cost.

Future works can include a more detailed modeling of the process to include ventilation, control panels, and wastewater and air treatment costs since these are also dependent on galvanizing techniques and amounts of chemicals and metals involved.

It is also worth mentioning that the industry standard practice of pricing per kilogram of base part is extremely inaccurate, leading to underpricing in small and thin parts while overpricing in large and solid parts.

6. Acknowledgement

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