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Meliorating the Corrosion Tester for Galvanising Steel Production

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***Abstract*—In the hot-dip galvanising process, the molten zinc will corrode steel. The molten zinc corrosion tester has been developed to simulate the working condition in a zinc pot to find the best powder parameters for corrosion prevention. However, the original design of the tester may cause severe zinc oxidation and produces dross floating on the surface of the zinc pot. A large amount of unwanted dross must be removed to prevent interruption to the operation of specimens. In order to reduce the amount of dross, this study applied TRIZ methodology to develop an effective tester which minimised the formation of dross. The results demonstrate that the newly created tester is able to extend 160% of continuous operation time and reduce 61.5% of zinc waste. This method could be further applied in other rolls in hot strip mills and cold strip mills.**

***Index Terms*—TRIZ, molten zinc, corrosion**

I. Introduction

Zinc hot-dip galvanising is one of the most effective methods for the corrosion protection of ferrous materials. Using this technique, the ferrous substrate is immersed in a bath of molten zinc and covered by a zinc coating with an average thickness of a few μm. The procedure in a continuous galvanising line (CGL) is demonstrated in Figure 1. It starts from raw sheets preparation, pre-galvanising preparation, hot dipping, and finally post-galvanising treatment.

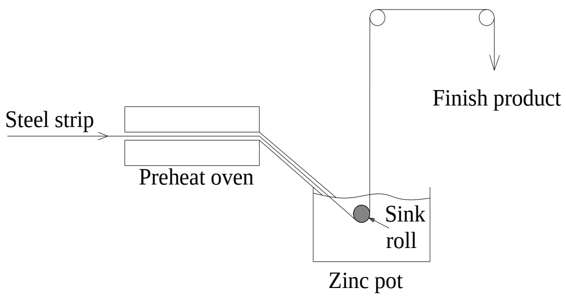

Figure 1. Schematic of a continuous galvanising line

Zinc coatings increase corrosion resistance of steel in several ways. As a barrierlayer, a continuous zinc coating separates steel from the corrosive environment [1]. A sink roll is used in the zinc pot to transport the steel sheets. However, molten zinc corrosion would occur on the surface of the sink roll and affect the quality of the galvanised steel sheets.

To develop a highly resisting coating against molten zinc corrosion so as to extend the service life of the rolls and to maintain the quality of the galvanised steel sheets [2][3][4], a molten zinc corrosion tester has been set up to simulate the working condition in a zinc pot. This tester has been developed through long testing until specimens have been out of order. The main feature of the tester is to find the best powder of specimens in the molten zinc. Four specimens can be applied at a time. That is, coatings of four different parameters are tested simultaneously, and the best coating material will then be decided. Different thermal spray powders are sprayed by the same spray parameter. Those specimens are subsequently tested to decide the best one. The goal of the tester is to find the best power parameter. The thermal spray technique of the sink roll is finally established to apply in the CGL in the steel mill. Figure 2 illustrates a schematic plot of the tester.

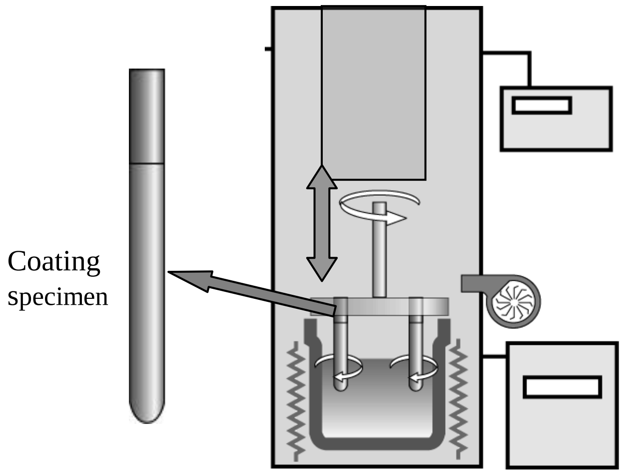

Figure 2. Schematic plot of the molten zinc corrosion tester

On the surface of a zinc pot, the molten zinc is active and will be oxidised easily. The specific gravities of zinc and zinc oxide are 7.17 and 5.61 respectively. The melting point of zinc oxide is 1975℃, which is far above the melting point of zinc at 420℃. Therefore, zinc oxide will float on the surface of the molten zinc. Once a layer of zinc oxide is formed on the surface, it will help to protect the fresh zinc against from further oxidation. However, if the layer of zinc oxide is stirred, more fresh zinc will be exposed to the air and more zinc oxide will form. When solid zinc oxide is accumulated to a certain level, it will eventually affect the rotation of the specimens [2][5]. Therefore, it is a must to periodically clean zinc oxide and refill zinc materials. The goal of the present

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study is to develop a new molten zinc corrosion tester to minimise the oxidation so as to decrease the frequency of interruption as well as the waste of zinc and to improve the test efficiency and accuracy.

TRIZ is an acronym for Russian "Теория решения изобретательских задач". It means "the theory of solving inventor's problems" [6][7][8]. TRIZ includes different problem solving tools, such as Contradiction Matrix, Inventive Principles, Trends of Technology Evolution, IFR (Ideal Final Result), S-Field (Substance-Field) Analysis, ARIZ (Russian acronym of алгоритм решения изобретательских задач, Algorithm for Inventive Problem Solving), Trimming Rules, Psychological Inertia Tools and Subversion Analysis [6]. In this study, TRIZ was used to solve the oxidation problem of the molten zinc corrosion tester.

The remainder of the paper is organised as follows: Section 2 describes how the study and analysis are carried out. The solution and discussion of the findings are presented in Section 3. Finally, we draw our conclusions in Section 4 including contributions and future applications.

II. Case Study and Analysis

The forming of zinc oxide is due to the fact that fresh zinc is exposed to the surface of the molten zinc and reacts with oxygen. In the present study, if the layer of zinc oxide on the surface of the zinc pot does not break, fresh zinc will not contact with the air. On the other hand, if oxygen is prevented from getting into the testing environment, zinc oxide will not be formed, either. Conclusively, two factors are defined. One is the breaking of zinc oxide layer, and the other is prevention of oxygen intrusion. If one of the above factors is removed from the testing system, the oxidation problem of the molten zinc corrosion tester can possibly be solved. Obviously, oxygen is the primary factor causing zinc oxide. Following the Function Attribute Analysis, the issue of the molten zinc corrosion tester is presented in Figure 3.

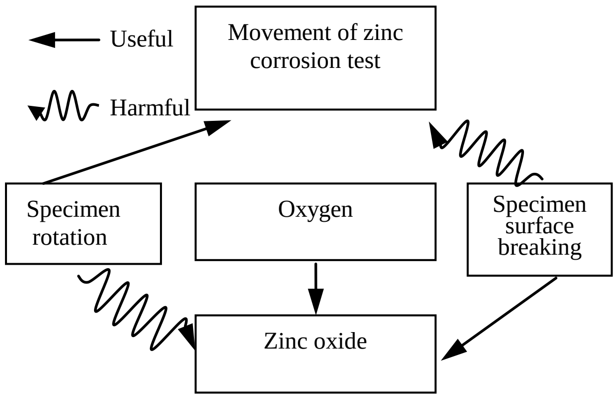

Figure 3. Function Attribute Analysis

In this study, S-Field Analysis was used to acquire effective methods. Specimen S_2 is driven by mechanical force to stir zinc S_1. However, this will cause unwanted oxidation from S_2 to S_1 and lead to a harmful effect. According to TRIZ, when a harmful effect appears in a system, there are several methods to solve the problem. The method "Add a new substance" was used in this study, and the harmful effect is expected to be removed by introducing a third substance. To be more specific, if an object S_3 is inserted between S_1 and S_2, the harmful element may be removed from the system, as illustrated in Figure 4.

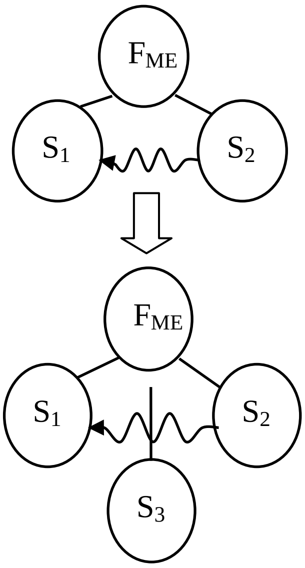

Figure 4. Suggestion of solving a harmful effect.

III. Solution and Discussion

Zinc oxide layer is originally effective in protecting objects on the molten zinc surface. However, the problem here is that stirs by the specimen will break the static oxide layer and lead to more fresh molten zinc to be exposed to the air. To prevent further oxidation, adding a static protecting layer between molten zinc and the air is necessary. In the 40 Inventive Principles, it was found that #24 Intermediate and #39 Inert Atmosphere are the possible solutions to solve this problem [6]. By referring to similar cases, a layer of zinc oxide powders was sprayed on the molten zinc surface and nitrogen gas was injected, as shown in Figures 5 and 6.

Although a protective layer was introduced to the system, the oxidation problem, however, remains. That is because the protective layer is not static, and it will be broken by the stirs of the specimens. In addition, the protecting ability of nitrogen injection is also limited as the zinc pot is not a closed system and air can get into the zinc pot, and then the molten zinc gets oxidised.

Referring to the contradiction matrix in TRIZ, the problem we need to solve here is physical contradiction. That is, molten zinc needs to be stirred in the experiment and also it needs to keep static for less oxidation. This contradiction could be solved by the Space Separation Principle with which the molten zinc is stirred but the surface keeps static. Further referring to the case of #13 Inversion, the problem can be resolved by fixing specimens in place with molten zinc flowing around. Through applying the technique in the Sub-Field Model, S_1 is the molten zinc while F_{ME} and S_2 still need to be defined. In order to have the molten zinc flow while the specimens are fixed, a propeller is considered to be used (see Figure7).

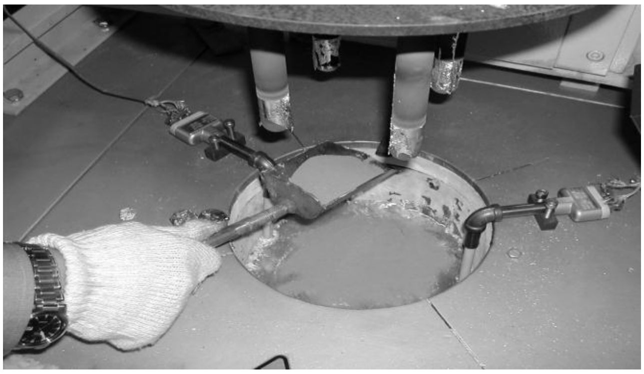

Figure 5. Spraying zinc oxide powders

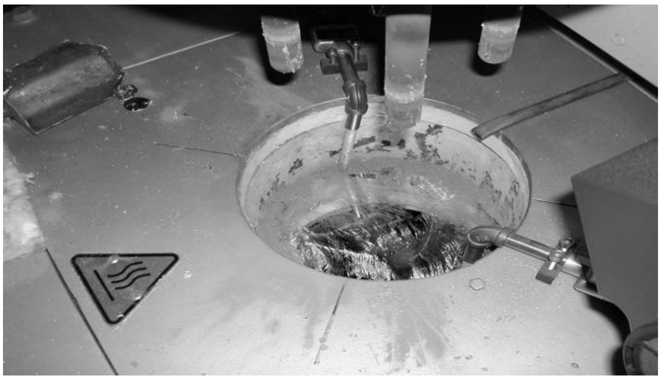

Figure 6 Spraying zinc oxide powders

Figure 7 Spraying zinc oxide powders

Therefore, in the Sub-Filed Model, S_2 is defined as a propeller and FME as the driving force of the propeller. The molten zinc is stirred by the propeller. It should be noted that only the propeller is rotated by the force FME, and specimens are fixed and the surface of the molten zinc is static. This combined solution to the oxidation problem of the molten zinc corrosion tester is displayed in Figure 8.

Figure 8. The combined solution to the oxidation problem of the molten zinc corrosion tester

It is the new design of the molten zinc corrosion tester that the molten zinc surface can keep static very well. In the previous tester, testing has to be interrupted and zinc oxide should be removed every 40 hours. Interestingly, this newly developed tester demonstrates a continuous operation without any interruption for 104 hours, showing 160% of extension of continuous operation time (see Figure 9). This certainly demonstrates a great improvement.

Encouragingly, the revised version of the tester not only reduces interruption frequency but also saves a lot of zinc materials. Previously, a molten zinc corrosion tester used to form 2.6 kilograms of zinc oxide every day, but now the newly created tester produces merely one kilogram of zinc oxide daily. This study is a 40-week project. It is seen that by employing the new method, loss of zinc will be reduced from 728 to 280 kilograms. This indicates an improvement of 61.5% in reducing zinc waste (see Figure 10). It is therefore proven that the new method is significantly efficiently and effectively.

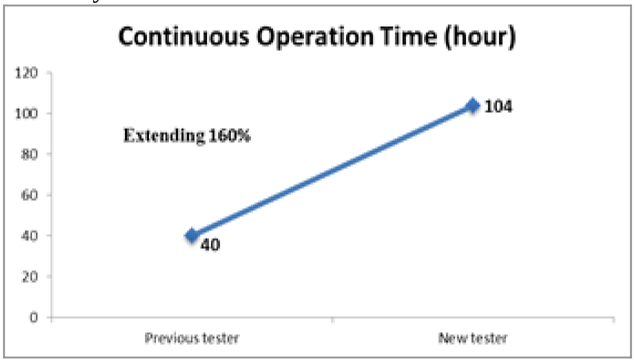

Figure 9 Extension of continuous operation time

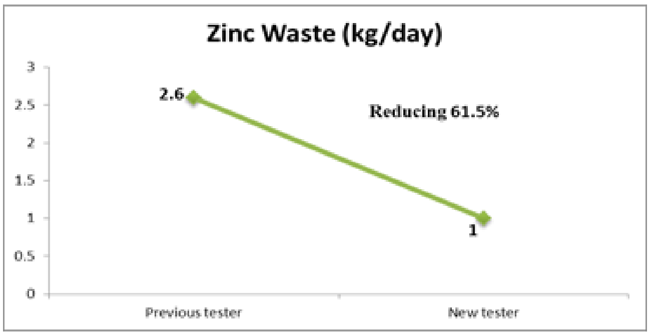

Figure 10 Reduction of zinc waste

IV. CONCLUSIONS

By applying the TRIZ methodology, the newly developed tester is able to solve the oxidation problem of the molten zinc corrosion tester. Technologically, this new design saves a lot of zinc materials. 2.6 kilograms of zinc dross were generated each day by the previous tester, while the newly created tester produces only one kilogram of zinc oxide per day. Therefore, a total of 1.6 kilograms of zinc is saved every day, which reduces about 61.5% of zinc waste. On the other hand, testing was interrupted and zinc oxide should be removed every 40 hours in the previous tester, while this developed tester demonstrates a continuous operation without interruption for 104 hours. This shows 160% of extension of continuous operation time. It can be concluded here that the molten zinc corrosion tester is running more efficiently after utilising this new method. The goal of minimising the amount of zinc oxide and maximising steel quality is thus achieved in this study specifically through this newly created molten zinc corrosion tester.

Due to such molten zinc corrosion testing, the development of thermal spray coating on sink rolls is better than expected. Practically, through prolonging the lives of the rolls, the frequency in maintenance can be minimised and the quality of CGL can be improved. This study will contribute to saving large amount of maintenance cost for hot zinc pots. Additionally, such technology can be further adapted in other applications, such as bridle rolls, deflector rolls, furnace rolls and looper rolls.

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