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3D-Evaluation Method for Descaling Capability of Hot Strip Mill

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Good surface quality of hot rolled steel strip has been demanded in recent years and the major defects found are rolled in scale caused by dysfunctional descaling. Although many theories have been postulated to predict the effectiveness of descaling based on nozzle type and pump capacity, an online evaluation of descaling is still not available. In order to ascertain the nozzle performance and descaling capability of the hot strip mill (HSM), we started to develop offline and online erosion pattern testing. After the analysis of the erosion pattern by 3D scanner, the distribution of the descaling impact force and overlap within adjacent nozzles could be evaluated. Consequently, the test results can be used as important data to optimize the descaling of HSM.

Keywords: HSM (Hot Strip Mill), Descaling, Rolled in scale, Impact force, Erosion pattern

1. INTRODUCTION

Descaling is a key process of hot rolling, especially when a good surface quality of the hot rolled products is demanded. Many studies have been made on the descaling technique of the hot strip mill (HSM) process [1-3]. The key descaling parameters include the facility, the descaling performance and the descaling conditions (Figure 1). The earlier studies always pay much attention to the impact force to estimate the effectiveness of descaling, but the true data are still unknown. Thus both inspection procedure and equipment improvement became necessary to achieve better descaling capability. Hence, an estimation method of the descaling impact force produced by a single nozzle and by the entire header should be established. In this paper, we have developed an erosion testing procedure to estimate the impact force for a nozzle under specific spray conditions. In addition, the concept of this method can also be applied to estimate the performance of the descaling header. Besides, we have found that the applied impact force should be regarded as the erosion weight loss per second. For the better accomplishment of the overlap descaling, we also have to take the distribution of the impact force into consideration.

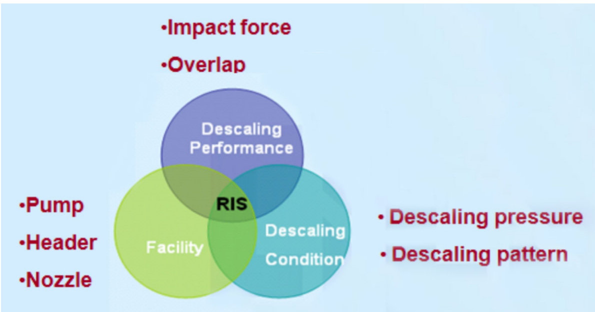


Fig.1. Conjunction graph of rolled in scale and descaling.

2. EXPERIMENTAL PROCEDURES

2.1 Offline Erosion Pattern Test

Nozzle manufacturers have developed their own techniques, by use of pressure sensors or the weighting method, to detect the impact force and its distribution. The erosion test is a common way to measure the performance of the nozzle. This method also provides a visual sample to estimate the distribution of the impact force of a single nozzle under specific spray conditions; however, the testing conditions have to comply with the situation of different HSM descalers. To develop an advanced offline erosion pattern test, we established a set of equipment (Figure 2) to carry out the test. The equipment included a 300bar pump with variable frequency drive (VFD) that can produce the same high pressure water jet to simulate descaling system. We also prepared aluminum alloy plates as the specimen owing to its low hardness. After testing, the aluminum alloy was eroded and a mark remained on the plate, which was examined using the 3D scanner technique. The shape, length, width, depth, and the total erosion loss revealed the impact properties of the nozzle under specific spray conditions.

Fig.2. The equipment for offline erosion pattern test.

2.2 Online Erosion Pattern Test

The offline single nozzle erosion pattern test cannot represent the descaling capability of the HSM because during production that capability can be affected by various factors such as piping, nozzle condition, and pump power. In order to investigate the online descaling performance, an erosion test was applied in the HSM. Accordingly, a testing plate (a dummy transfer bar), attached to aluminum alloy plates, was prepared to inspect the descaling effectiveness. Figure 3 shows the positions of the attached aluminum alloy plates designed to correspond to the positions of specific descaling headers.

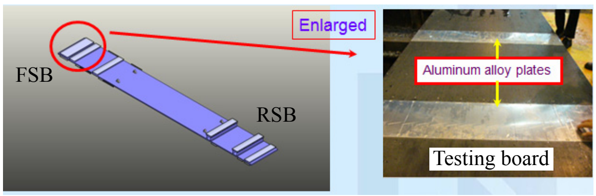


Fig.3. The testing board for online erosion test.

Before testing, careful alignment of the testing plates is necessary to make sure that the aluminum plates correspond precisely to the descaling positions. Then, the high pressure water jet is operated for several minutes to erode the aluminum plates. After testing, aluminum plates with descaling patterns obviously eroded by different headers can be offloaded for further analysis.

2.3 3D Morphology Analysis

According to the nozzle manufacturer, the erosion weight loss result is dedicated for a particular nozzle by the weighting method. Therefore, the weighting method cannot be applied to measure a series of nozzle erosion weight losses through marks on the aluminum plates obtained by online erosion testing. In order to break the bottleneck for the online erosion pattern analysis, we used a 3D scanner (Figure 4) to capture the digital features of every erosion mark. As a result, the erosion weight loss of each mark can be calculated according to the volume and density of the aluminum alloy.

Fig.4. 3D scanner for capturing the 3D morphology of marks on the aluminum plate.

3. RESULTS AND DISCUSSION

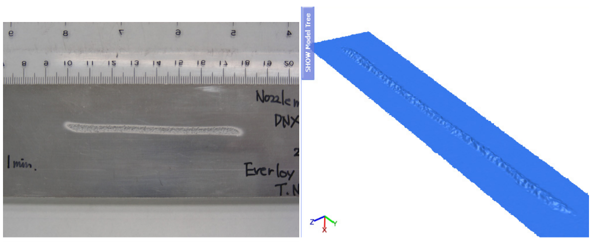
3.1 Investigation of the Descaling Impact Force

Under specific water pressure and spray time interval, the impact force can be predicted according to hydrodynamics. Thus the shape of the water jet used for descaling is a triangle rather than a theoretical cylinder. However, the actual impact force of the descaling jet is very complex and has to be evaluated by precise fluid analysis which is still under investigation. In general, the impact force of the nozzle depends mainly on the nozzle design and spray distance. In order to optimize the descaling system, we have to establish a credible way to investigate the impact force.

3.1.1 Traditional Analysis Method of Offline Nozzle Pattern Test

Nozzle manufacturers usually use the pressure sensor or erosion test to estimate the impact force of the water jet [1-2], the pump pressure and flow rate are always smaller than the online facility. The pressure sensor method provides real-time data of the impact force in both the horizontal and vertical directions[4-5]. This method requires an accurate calculation model to calibrate the impact force based on the measured pressure data. Nevertheless, the precision is in relation to the calculation model and the sensitivity of the measuring instruments. Another estimating method is the erosion test which can obtain a substantial sample eroded by water jet. The mark on the aluminum plate caused by the erosion of water jet could also provide us with some information about the distribution of the impact force.

To replace the traditional analysis methods, we used a 3D scanner to investigate the impact force of the descaling water jet obtained by the erosion test. Figure 5(a) shows a testing specimen which has been eroded by a single nozzle at certain conditions. The erosion mark is very clear and can be analyzed by 3D scanner (Figure 5(b)). The 3D digital data, called point cloud, reveals the physical properties of the mark, such as volume, depth, width and length.



(a) (b)

Fig.5. (a) The specimen of erosion test and (b) the 3D morphology captured by 3D scanner.

3.1.2 Nozzle Performance Evaluation

Consequently, the erosion weight loss can be calculated and, sometimes, only regarded as the impact ability rather than the absolute data of the impact force because the weight loss varies with the erosion time and spray distance (d). Table 1 exhibits a series of mark data of nozzle A tested at 170mm under 240bar for 30s, 60s, 90s, 120s and 150s. Figure 6 shows that the erosion weight loss is proportional to the erosion time under specific nozzle conditions such as water pressure and spray distance. Accordingly, the slope of the curve which indicates the erosion weight loss per second is suggested to be credible information about the impact force (IF). Figure 7 also shows that the IF varies with spray distance (d) for nozzle B. Interestingly, the curve of IF versus distance (d) reveals a linear line rather than a conic section. This implies that the effective IF applied on the aluminum plate is also proportional to the spray distance. We think that the IF value can be named as the applied impact force which is more credible for us to estimate the descaling system.

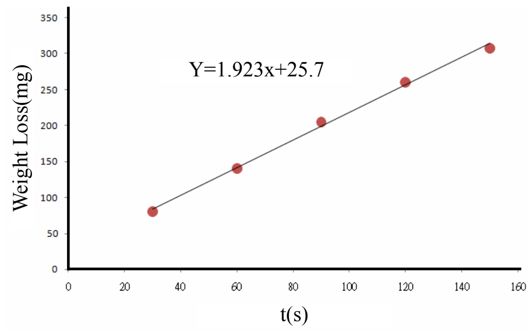


Fig.6. Diagram of erosion weight loss versus erosion time(t).

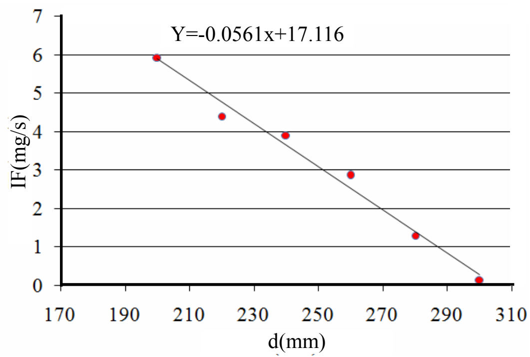


Fig.7. Diagram of applied impact force (IF) versus spray distance (d).

Table 1 A series of mark data of nozzle A tested at 170mm under 240bar for 30s, 60s, 90s, 120s and 150s

Spray distance (mm)	Pressure (bar)	Erosion time (s)	Erosion weight loss (mg)	Erosion volume (mm^3)
170	240	30	80	218
170	240	60	140	382
170	240	90	205	560
170	240	120	261	713
170	240	150	308	841

3.2 Performance of the Descaling System

A descaling system is indispensable for a hot strip mill. The descaling system performance is dominated by the pressure and the arrangement of the nozzles. According to the hydrodynamics, high pressure will produce a water jet with a high impact force. In addition, the physical design of the descaling header also affects the entire descaling capability[6].

Figure 8 shows the schematic diagram of typical descaling jets that will interfere with each other so that the practical descaling area will be reduced[7-8] (Figure 9). These phenomena inform us that we have to consider both the impact force and the overlap to achieve effective descaling.

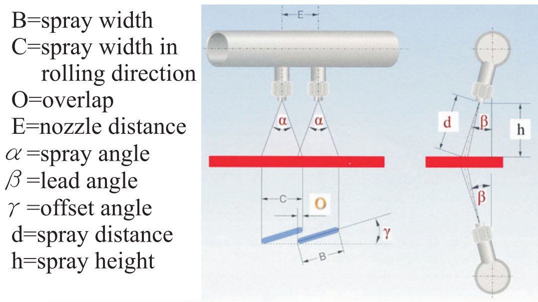


Fig.8. Geometrical relationship between nozzle conditions and spray pattern.

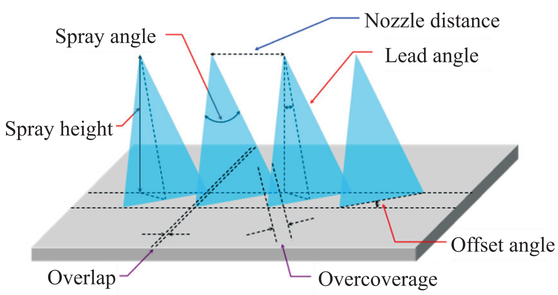


Fig.9. Overlap and overcoverage results affected by nozzle conditions and spray pattern.

3.3 Overlap Analysis of Online Descaling System

Geometrical theories are referenced to estimate the overlap between descaling jets (Figure 8 and Figure 9). However, interference between the water jets may take place so that the actual overlap cannot be calculated just by the geometrical method. Actually, we have to take the interference into consideration for overlap estimation. In order to comprehend the actual spray results of the descaling system, we prepared a testing board attached to the aluminum plates (Figure 3) for the online erosion pattern test. Figure 10 shows an aluminum plate which has been eroded under 160bar for 30s. The marks on the aluminum plate, called the descaling pattern, exhibit the actual performance of the descaling system. Figure 10 shows that the overlap can be measured to be 8mm (half the spray width) which corresponds to the geometrical relationship of the nozzles. As the spray distance is reduced to 50mm, the descaling pattern reveals shorter marks and zero overlap in the aluminum plate (Figure 11). With these results we can decide which case can provide the optimum descaling capability for the HSM.

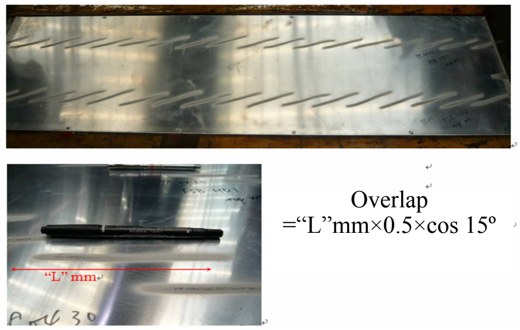


Fig.10. The specimen of the online erosion test under 160bar at 250mm.

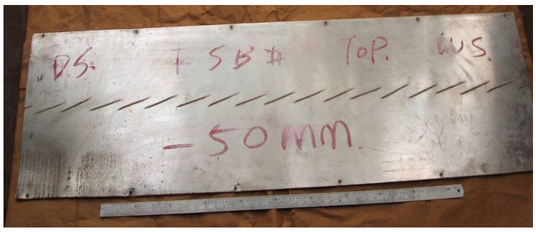


Fig.11. The specimen of the online erosion test under 160bar at 200mm (shorter 50mm).

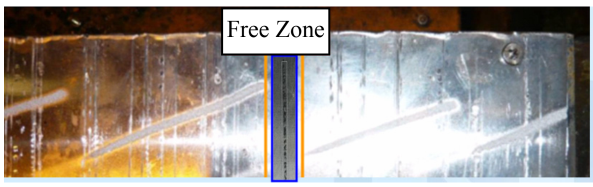


Fig.12. Free zone existing between water jet inducing incomplete descaling.

3.4 Dysfunctional Descaling and Rolled in Scale

According to another descaling pattern obtained by a higher impact force (Figure 12) a free zone exists between the water jets and induces incomplete descaling under higher pressure (240bar) and shorter spray distance (160mm). Apparently, even when the overlap is designed by the geometrical method, the actual spray results should be estimated by online erosion pattern tests. Figure 12 shows that incomplete descaling is the root cause to induce primary rolled in scale. In addition, interference between the water jets may take place under higher impact force and cause a mismatch between geometry and the actual sprays. As a result, the online erosion pattern test is a useful method to optimize the descaling system.

4. CONCLUSIONS

According to the erosion test of a single nozzle traditional erosion pattern test can be applied to ascertain HSM descaling capability online as well. The 3D morphology analysis method can help us investigate the impact force and overlap between the water jets. Under a high impact force, interference will take place and cause insufficient overlap. Hence, the better way to optimize descaling is adjusting the IF and actual overlap by the erosion pattern test results.

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