Research on Heat Treatment Process Optimization of Welding Workstation under New Engineering Background

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Abstract: With the development of new engineering, more research began to transform to energy-saving technology in equipment manufacturing industry. Studies about measurement and analysis of residual stress after surfacing of Heat exchanger tube sheet & the causes of PWHT (post weld heat treatment). Results revealed that the residual stress distribution presented certain trends. PWHT have a limited impact on general trend. Strongest point of stress appears in the ends of test piece or at the surface center of test piece. To some extent, annealing time of 300 minutes is more conducive to removing the residual stress than 90 minutes. Annealing temperature of 610°C has more significantly effect than 580°C. Stress of measuring point reduced on average by 40%. At 580°C to 610°C and when annealing time is from 90 minutes to 300 minutes, main cause of removing the residual stress is annealing temperature.

Keywords: New engineering; Energy-saving process; Residual stress; Annealing; Process optimization;

1. Preface
With the development of new engineering, new research on energy saving in equipment manufacturing has appeared. Among them, the research on energy-saving technology of post welding heat treatment widely existing in pressure vessels has gradually attracted people's attention. Heat exchanger is a kind of general equipment, applied in many industries, such as chemical industry, refinery industry, power industry and electricity industry. Heat exchanger tube sheet (TS) is a major part, separate medium, suffer corrosion and work under pressure from tube pass and shell pass. A low strength material is added to the surface of tube sheet by surfacing welding to enhance the ability of corrosion resistance.
At present, PWHT, to a certain extent, can remove residual stress. But PWHT need too long time and consume many much energy, is hard to implement in industrial production. Above all, studies about measurement and analysis of residual stress after surfacing of Heat exchanger tube sheet & the causes of PWHT is a main cause to optimize PWHT.
Tests include test piece and other relative equipment, such as automatic submerged-arc welding machine, measuring device, etc. Surfacing welding was performed as the actual working conditions. The residual stress was measured and data acquisition and processing by drawing the stress distribution curves. The stress values of measuring points after various kinds of annealing are treated in a similar way. Afterwards, factors
of surfacing welding are analysed. Studies provided some measuring methods and references for process optimization of PWHT.

2. Experiment method

2.1. Performing surfacing welding and measurement of residual stress

According to dimensions of heat exchanger tube sheet, test piece is forged from 20MnMo. It is about 1100.00 × 300.00 × 100.00 mm. Test piece is fixed on the substrate by spot welding during surfacing welding process. Physical model is shown in Figure 1.

![Stress corrosion of heat exchanger tube sheet.](image1)

![Test piece](image2)

Figure 1 Physical model

Surfacing welding was performed by automatic submerged-arc welding machine. Process starts from an end of test piece along the length direction according to zigzag path. Each layer thickness is approximately 0.5 mm. As shown in Figure 2 (b).

Through blind-hole method, residual stress of surfacing layer was measured by ASM3.0 Residual stress tester. The type of strain rosette is special for blind-hole method, \((\text{CA}) \ 0^\circ \sim 90^\circ \sim 45^\circ\) three-dimesional rosette gauge. Gauge rosettes paste on the surface of the test piece. Through special formula of blind-hole method, residual stress of measuring point is calculated by measuring point strain. There are 7 points as shown in Figure 2 (a).

![The positions of measuring points](image3)

![Test piece after surfacing welding](image4)

Figure 2 Test piece after surfacing welding and the positions of measuring points

2.2. PWHT (post weld heat treatment)

According to DGS8201, PWHT was performed by chamber electric furnace (IKRG-30-JL). Two test pieces after surfacing welding on the same conditions were marked TS_1#, TS_2#, respectively for annealing with 580°C, 610°C. The parameters are shown in Table 1.

| Tube sheet | Temperature (°C) | Primary time (minute) | Cumulative time (minute) |
|------------|------------------|-----------------------|--------------------------|
| TS_1#      | 580              | 90                    | 300                      |

Table 1 Annealing of PWHT parameters
3. Testing results & Discussion

3.1. Analysis of measurement results on residual stress

The stress value measured is drawn in the curves <Figure3>. The stress distribution curves after surfacing welding indicate that the maximal axial stress of TS_1 is 319.2MPa <Figure3 (a)>, appeared at the surface center, the value of TS_2 is 353MPa appeared in the ends of test piece. There is a distribution trend presented by curves both of TS_1 and TS_2 that stress decreases from both ends of test piece, rises after reaching a minimum, reached a maximum in almost neutral. The general distribution trend implies that more apparent temperature change in some parts of test piece induces more obvious deformation, as a result, more stress induced by deformation. In general, the strongest point of stress is not appeared in the same position, but residual stress distribution of TS_1 and TS_2 presented a consistent tendency.

![Stress distribution change with 580°C PWHT](image1.png)

![Stress distribution change with 610°C PWHT](image2.png)

**Figure 3** The stress distribution of test piece along the length direction

As the stress distribution curves in Figure3 (b) shown that the distribution tendency after 610°C PWHT is in accordance with the trend after surfacing welding. The similar situation appeared with 580°C PWHT. As the curves in Figure3 (a) shown, some changes appeared in the stress distribution curves after 580°C PWHT, the margin fluctuation of curve becomes smaller, but the general tendency of the stress distribution have not change. All of this data indicates that characters of the stress distribution have not much change after PWHT, and the stress value along the length direction changes more gently.

3.2. Main causes of PWHT

In the form of percentage, a summary about degree of reduction of measuring points after PWHT was shown in Figure4. As Figure4 shown, maximal deduction of TS_1# after 580°C PWHT which annealing time is 90 minutes is 46.97%, appeared in the end of test piece. Minimal deduction appeared in the point about 1/5 of test piece, the percentage is 7.39%. Average of measuring points is 29.88%. When annealing time is 300 minutes, maximal deduction is 57.59%, appeared in the end. Minimal deduction is 32.76%, appeared in 2/5 position of TS_1#. Average value is 43.61%. All of these data show that average degree of deduction after 580°C PWHT which annealing time is 300 minutes is more 17.73% than the value when annealing time is 90 minutes. Meantime, the distribution about degree of deduction became more gently when annealing time is 300 minutes.
When it comes to TS_2 performed 610℃ PWHT, an anticipated data appeared. After 90 minutes, maximal value is 77.43%, appeared in 3/5 position of test piece. In the end of TS_2, degree of deduction became minimum, is 58.73%. Average value is 69.54%. When annealing time became 300 minutes, the corresponding data became that maximal value is 86.62%, appeared in 2/5 position, minimal value is 74.50%, appeared in the end of TS_2, average value is 81.34%. In summary, average value of “300 minutes” is more 11.8% than “90 minutes”. The distribution of deduction has few differences between two sets of measurement shown in Figure4 (b).

4. Conclusion

In general, the residual stress distribution of TS_1# presents a similar trendency in accordance with TS_2#. The residual stress decreases from both ends of test piece, rises after reaching a minimum, reaches a maximum in almost neutral. After PWHT, the stress distribution become more gently, and characters of the stress distribution have not much change.

Annealing temperature is the main cause of PWHT at 580℃ to 610℃ and when annealing time is from 90 minutes to 300 minutes. Average degree of deduction after PWHT which annealing time is 300 minutes is about more 10%~20% than the annealing of 90 minutes. Also, average increased effect of measuring points performed in 610℃PWHT is approximately more 40% than that in 580℃PWHT.

Experiments provide the first-hand information about measurement and analysis of residual stress after surfacing welding of Heat exchanger tube sheet & the causes of PWHT (post weld heat treatment). Studies provided some measuring methods and references for process optimization of PWHT.

5. Acknowledgement

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6. References

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