Reducing Costs and Energy Usage During Nitrocarburizing Operations in a Commercial Heat Treatment Plant

Nipon Taweejun[1], Natnaree Senaweenin[1], Putthitorn Dechophop[1], Sankum Nusen[2], Torranin Chairuangsri[2], John TH. Pearce[2]

[1] *Thai Tohken Thermo Co. Ltd, Chonburi 20000 Thailand*
[2] *Department of Industrial Chemistry, Faculty of Science, Chiang Mai University, Chiang Mai 50200 Thailand*

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1. Introduction

During commercial nitrocarburizing operations production costs may be reduced and sustainability improved by increasing energy efficiency and by optimizing the consumption of the gases needed for furnace atmosphere control. Potential savings may be gained via reductions in process time and/or in the amount of treatment gas used. The latter may possibly be achieved by reducing the treatment gas flow rate into the nitrocarburizing furnace and also by reducing the ratio of ammonia gas used in the gas mixture. By producing a hard surface compound layer, normally 10-20 µm thick, which consists of complex carbonitrides, nitrocarburizing of components not only increases their wear resistance but also improves resistance to fatigue and corrosion [1-4)]. When making changes to the process, it is therefore critically important that the correct microstructure, properties and characteristics of the nitrocarburized surfaces and the underlying substrates of the treated components are maintained, and that overall quality is not compromised.

As part of a wider process development study, this paper focuses on the effects of reducing the treatment time on not only energy usage costs but also on the resultant microstructures, thickness and properties of the nitrocarburized compound surface layers and the microstructure of their support substrates.

2. Experiment

Nitrocarburizing can used to treat various types of steel, however, the present study is limited to the treatment of low %C (0.043 wt.%C), which corresponds to the SPCC steel of the Japanese industrial standard. Various trials were carried out on dummy 400kg charges of the low C-steel in a commercial 2 chamber nitrocarburizing furnace using the normal treatment temperature 570°C for 3 hours and reduced times of 2.5 and 2 hours for different flow rates and NH_3/Rx(propane) gas ratios. A standard three-level orthogonal array, as shown in Table 1, was used for the experimental design to study the effects of the 3 main factors i.e. treatment time, gas flow rate and NH_3 gas ratio.

In compliance with JIS G 0553 the specimens were carefully sectioned perpendicular to the nitrocarburized surface, polished and etched in a solution of 5 ml HNO_3 and 95 ml methanol to reveal the compound layer. The thickness of the layer was measured at x400 using an optical microscope equipped with software for image analysis (Nikon: DS-R11/NIS elements). Surface hardness levels were measured using microhardness machine (Future tech: FM-800) with a 100-g load. Microstructure and porosity was assessed using a scanning electron microscope (JEOL, JXA-ISP100)

Table 1 Experimental conditions

Trial No.	Total flow in chamber (m^3/hr)	Time (hr)	Gases Ratio	NH_3 flow (m^3/hr)	RX-gas flow (m^3/hr)
1	17	3.0	1.0 : 0.7	10.0	7.0
2	17	2.5	0.9 : 0.7	9.5	7.5
3	17	2.0	0.8 : 0.7	9.0	8.0
4	15	3.0	0.9 : 0.7	8.5	6.5
5	15	2.5	0.8 : 0.7	8.0	7.0
6	15	2.0	1.0 : 0.7	9.0	6.0
7	13	3.0	0.8 : 0.7	7.0	6.0
8	13	2.5	1.0 : 0.7	8.0	5.0
9	13	2.0	0.9 : 0.7	7.5	5.0

3. Results and Discussion

3.1 Surface Hardness and Compound layer thickness

The results for surface hardness and compound layer thickness are shown in Figure 1 and Figure 2, respectively. The surface hardness and the compound layer thickness of all trials were above the minimum requirement of 400Hv and 10µm respectively. However, to assess variation in the treatments a normal distribution was assumed and +/- 3 standard deviations about the mean value was estimated for both compound layer thickness and surface hardness as shown in Table 2.

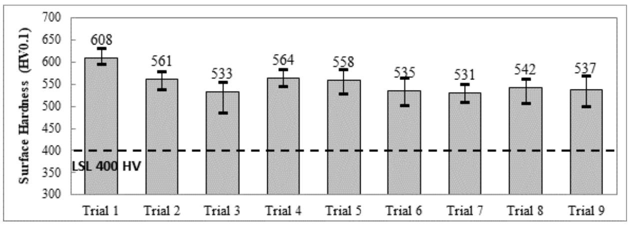

Figure 1. Average surface hardness of each trial.

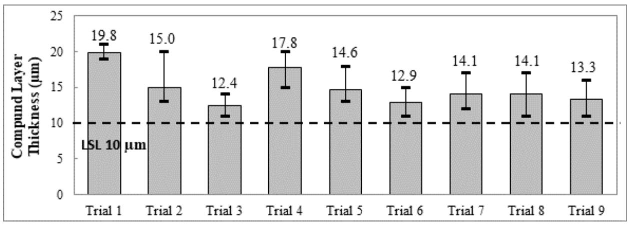

Figure 2. Average compound layer thickness of each test.

For a normal distribution it is expected that 99.73% of the values in each case will be between the (mean – 3s) and (mean + 3s) values. Table 2 shows that the hardness of all trials are at acceptable levels, while for the compound layer thickness at Mean-3s only trials 1, 4 and 5, can satisfy the minimum thickness level of 10µm.

Of all the 3 factors studied treatment time had the most effect on compound layer thickness, when treatment time was decreased, the thickness decreased significantly, while the other factors had lesser effects.

Table 2 Estimated +/- 3s values about the mean surface hardness (HV) and compound layer thickness (µm).

Trial	Surface Hardness (HV0.1)			Trial	Compound layer (µm)		
No.	Mean-3s	Mean	Mean+3s	No.	Mean-3s	Mean	Mean+3s
1	554	610	667	1	17.4	19.8	22.2
2	518	561	603	2	8.1	15.0	21.9
3	474	533	592	3	9.2	12.4	15.6
4	528	564	600	4	12.7	17.8	22.9
5	510	558	605	5	10.0	14.6	19.3
6	470	535	599	6	9.0	12.9	16.8
7	486	531	575	7	9.1	14.1	19.1
8	493	542	591	8	9.3	14.1	18.9
9	485	537	588	9	8.6	13.3	18.0

3.2 Microstructure and porosity analysis

Figure 3, shows the microstructure at the surface of the compound layers of trials 1, 4 and 5. Observation showed that although trial 1 provided the thickest compound layer, it also gave the largest amount of porosity in the compound layer, while trials 4 and 5 gave less porosity. This is due to a higher nitrogen activity in the extreme surface of compound layer of trial 1 [4].

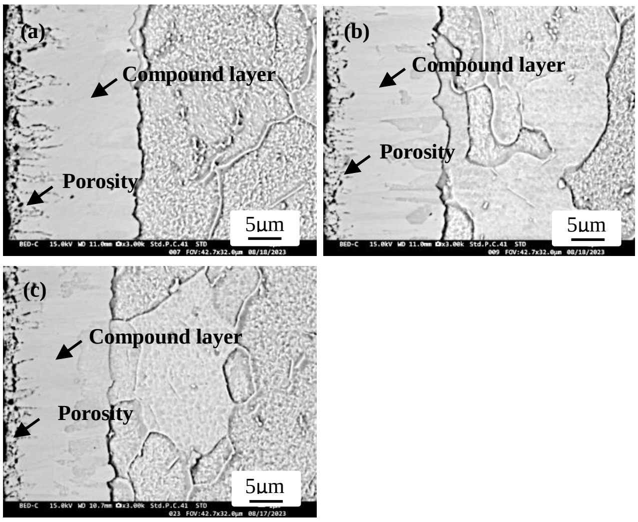

Figure 3. Microstructure and porosity at compound layer: (a) trial 1, (b) trial 4 and (c) trial 5.

3.3 Cost analysis

Table 3 lists the production cost i.e. electricity, propane and ammonia gas of each trial for one batch. It was found that the normal process conditions of time 3 hours, flow rate 17m^3/hr. and NH_3/Rx ratios 1.43 (trial 1) could be modified to 2.5 hours, 15m^3/hr. and 1.14 respectively (trial 5) and still provide a satisfactory compound layer having a mean thickness of 14.6 µm and mean surface hardness of 558Hv (Figure 1 and 2). Changing operation to this modified condition was estimated to give a 16.7% reduction in electricity cost, a 16.7% reduction in propane Rx gas cost and a 27.8 % reduction in NH_3 gas cost giving an overall saving of 25.6% in treatment cost.

Table 3 Production cost ratio (Compare to trial-1 Normal condition)

Trial No.	Electric	RX-gas	NH_3	Total
1	100.0%	100.0%	100.0%	100.0%
2	-16.7%	-10.7%	-14.8%	-14.8%
3	-33.3%	-23.8%	-28.2%	-28.7%
4	0.0%	-7.1%	-14.8%	-12.2%
5	-16.7%	-16.7%	-27.8%	-25.6%
6	-33.3%	-42.9%	-31.2%	-32.2%
7	0.0%	-14.3%	-6.5%	-6.1%
8	-16.7%	-40.5%	-26.0%	-25.5%
9	-33.3%	-47.6%	-29.6%	-31.2%

4. Conclusions

The study showed that treatment time has the most effect on compound layer thickness. Even though all the trial results are at acceptable levels, when considering the possible variation in the process by using -3s/+3s values about the mean, the acceptable trials are only trials 1 (normal), 4 and 5. In comparing porosity in the compound layer, trial 1 gave more porosity than trials 4 and 5.

In summarizing data for costs of utility usage, ammonia usage cost the most but reduction in treatment time has the most affect in reducing cost, because reduced time means reducing all facility use in that amount of time. When comparing the costs in trials that provide acceptable quality, trial 5 gave the lowest cost.

Hence trial 5 has potential to replace the normal conditions of trial 1 because it can not only give acceptable quality with respect to surface hardness, compound layer thickness and level of porosity, but also provide savings in the cost of production.

References

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