

EFFECT OF PROCESS PARAMETERS IN HOT DIP ALUMINIZING OF MEDIUM CARBON STEEL

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ABSTRACT - Surface is the only part of the component, which has to co-exist with external environment. Majority of engineering failures originates from the surfaces and components degrade in service leading to failures such as fatigue, wear, corrosion, and oxidation. The present study deals with the surface modification of steel base through diffusion of aluminium by hot dip aluminizing, for improving wear and corrosion resistance. The material chosen for study is medium carbon steel. Effect of varying dip times at different diffusion temperatures and times on the microstructure and microhardness of aluminized and diffused specimens was studied. The studies were conducted based on statistical techniques such as of Taguchi in order to reduce the experimentation efforts. Considering a non-porous surface and the increased case depth, the dip time of 3 minutes and diffusion temperature of 1023 K seems to be the optimum condition. However, higher diffusion temperature yielded porous surface and lower dip time showed a thin layer of case depth. The surface hardness of steel could be increased to a maximum of 1000 HV_{0.1} when aluminized and diffused. X-Ray diffraction studies have confirmed the presence of aluminides in the surface layer, which could be instrumental in the significant increase in surface hardness. This could be used for components in automotive and other engineering applications, where wear resistance is considered as critical.

INTRODUCTION - Surface modification by coatings has become an essential step to improve the surface properties such as resistance to wear, corrosion and oxidation. Various conventional techniques are utilized for depositing the desired material onto the substrate to achieve surface modification (1). In this study, an attempt has been made to improve the surface hardness of medium carbon steel by surface alloying with aluminum through diffusion. Aluminium coating provides steel with excellent oxidation and corrosion resistance at elevated temperatures up to 1173 K, and also with reasonable scaling resistance (2). Hot dip aluminizing is one of the most widely used processes for coating steel with aluminium to increase corrosion and oxidation resistance as well as hardness (3). The present study deals with effect of process parameters on the microstructure and microhardness of aluminized and diffused specimens.

In aluminizing, the surface layer is impregnated with aluminium to the specified thickness in the temperature range of 873-1273 K. It gives greater wear resistance, hardness and corrosion resistance. In order to identify a suitable aluminizing method, a comparison was made on the relative merits of the different aluminizing methods commonly reported in the literature (4). The results of this comparison are shown in Table 1. Based on this comparison, hot-dip aluminizing was chosen as the method of incorporating the alloying element into the steel samples studied.

Table 1. Comparative data on different aluminizing methods (Ref 4)

Process	Coating thickness (mm)	Relative cost	Absence of intermediate layer	Continuity of coating
Hot dipping	0.01-0.08	1 ^a	2	2
Cladding	0.01-0.13	2	3	1
Galvanic Coating	0.003-0.05	3	1	3
Metallizing ^b	0.05-0.50	4	1	4
Calorizing ^b	0.25-1.10	3	4	--

^a rating of 1 indicates the best results.

^b includes all types of diffusion coatings in solid mixtures

In accordance with the Al-Fe phase diagram in Figure 1, aluminium forms with iron solid solutions, intermetallic compounds and a eutectic composition. The solubility of iron in aluminium is extremely poor.

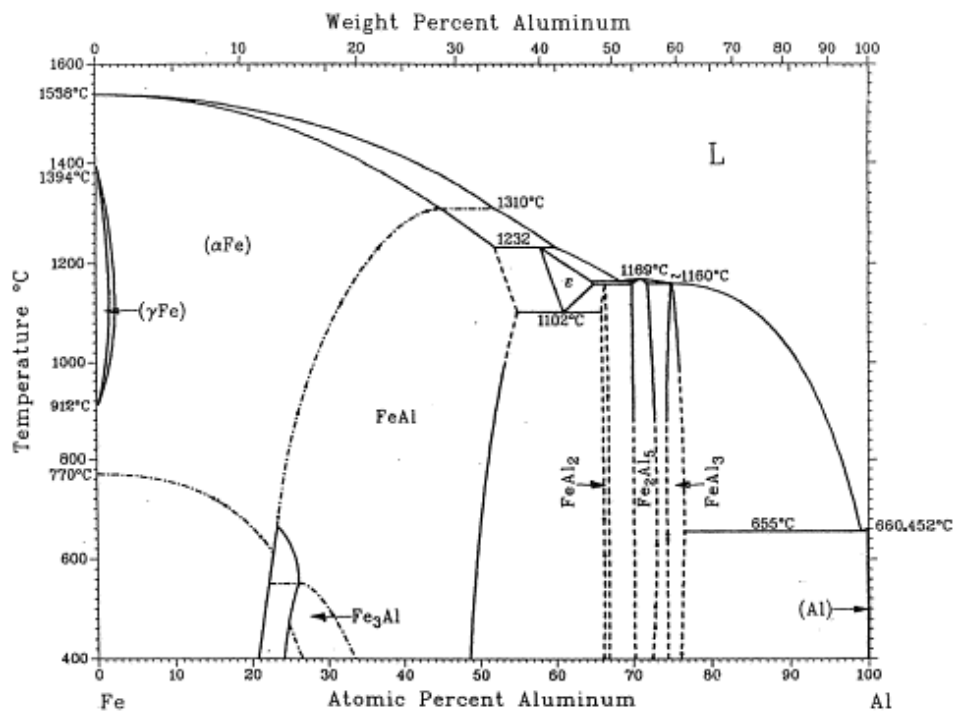


Figure 1. Aluminium –iron phase diagram (Ref 5)

MATERIALS AND METHODS

MATERIAL USED

BS970 grade EN 8 (or 080M40) steel was used as the substrate material. The substrate samples of 10 mm diameter, 60 mm length were used. The chemical composition of the material was analyzed using a direct reading vacuum spectrometer and is given in Table 2.

Table 2. Substrate Material Composition

Constituent	C	Si	Mn	P	S	Fe
%	0.36	0.17	0.743	0.032	0.026	balance

SURFACE PREPARATION

The specimens were thoroughly cleaned before aluminizing. Rinsing was carried out with 5% sulphuric acid solution for 3 minutes followed by water rinsing for 1 minute and then dried. The dried specimens were shot blasted with alumina grit for 5 minutes.

HOT DIPPING

The molten Al-11% Si bath was used for hot dipping. The bath temperature was maintained at 988 K (for higher fluidity). The addition of 11.6% Si reduces the melting point of aluminium from 933 K to 830 K thereby reducing the bath temperature. It also reduces the rate of growth of the diffusion layer $FeAl_3$ & Fe_2Al_5 (6). The steel specimens were dipped in the bath for time period of 1, 3 and 5 minutes, without any pre-treatment or fluxing. The specimens were gently shaken inside the bath to ensure good wetting. After dipping for the specified duration, the specimens were withdrawn and cooled in air.

DIFFUSION OF ALUMINIUM

Earlier studies (4) indicate that minimum temperatures of 773-793 K are required for formation of intermetallics and also that time should be 2 hours. However, other studies in the same literature (4) also indicate that temperatures of the order of 1073 K may be required. Hence, it was decided to employ 3 different diffusion temperatures and times as listed in Table 3. Taguchi technique was used successfully in the past in optimization studies (7, 8). Hence, in this study, the experiments are designed according to Taguchi's orthogonal arrays to reduce the experimentation efforts.

Table 3 Matrix experiment according to Taguchi's orthogonal array

Expt no	Dip time (min)	Diffusion temperature (K)	Diffusion time (hours)
1	1	873	2
2	1	1023	5
3	1	1173	8
4	3	873	5
5	3	1023	8
6	3	1173	2
7	5	873	8
8	5	1023	2
9	5	1173	5

After diffusion, the specimens were cooled to room temperature and cleaned in water to remove all traces of fireclay. The specimens were rinsed in 5% aqueous solution of caustic soda to dissolve any undiffused aluminium sticking to the surface.

OPTICAL MICROGRAPHY

For metallographic examination, the specimens were sectioned and mounted. To observe the microstructure of the surface coating layers formed by diffusion-treatment, the cross sections were mechanically polished using emery papers of grades 220– 600 and final polishing was carried out using diamond paste. The polished specimens were etched using 2% nital at room temperature for 3s.

MICROHARDNESS ON THE CROSS SECTION

The microhardness of the surface layers of the as aluminized specimens and aluminized and diffused specimens were measured using a ZWICK micro hardness tester. The hardness tests, including hardness traverse from the surface to the core were performed under an indentation load of 100g for 15 s

RESULTS AND DISCUSSION

OPTICAL MICROGRAPHY

Figure 2. shows as-aluminized specimen for dip time of 1, 3 and 5 minutes, consisting of the base material and the outer layer of aluminium coating. At dip time of 1 minute, coating appears broken at places and the coating adhesion appears poor. As the dip time increases, the coating thickness also increases as shown in Figure 2. At 5 minutes dipping time the coating thickness was around 120 μm .

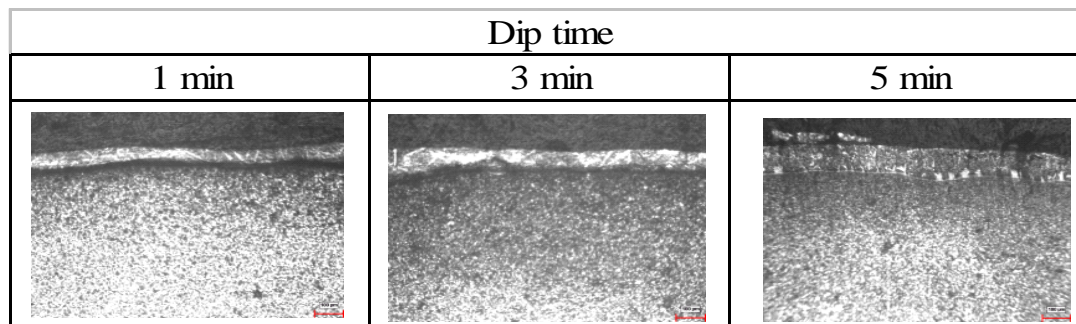


Figure 2. Microstructure of as aluminized specimens for various dip times

Figure.3 illustrates typical microstructures of aluminized and diffused steel specimens with varying process parameters. At higher diffusion temperatures of 1173 K, the coating appears to become more porous in nature, possibly due to oxidation. The lower dip time also yielded thin coatings which are de-laminated even in the low diffusion temperatures (873 K and 1023 K). The higher dip time (3 and 5 minutes) with lower diffusion temperature (873 K and 1023 K) showed a less porous diffusion layers.

MICRO HARDNESS

Figure.4 shows the hardness distribution from surface to steel substrate immersed at various levels. In the case of as dipped condition, the surface hardness of aluminized layer was found to be low around 50-200 $\text{HV}_{0.1}$. After the diffusion process, the surface hardness of the EN 8 steel increased to a maximum of 1000 $\text{HV}_{0.1}$. This is due to the pick up of aluminium by steel


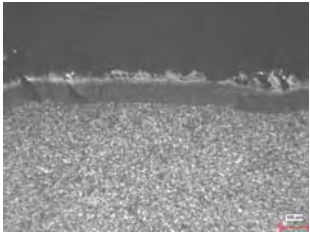

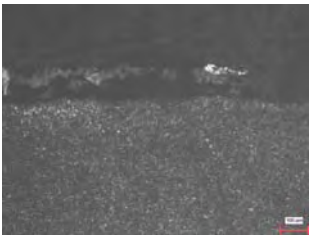
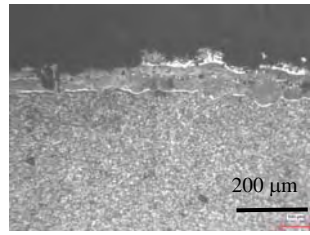
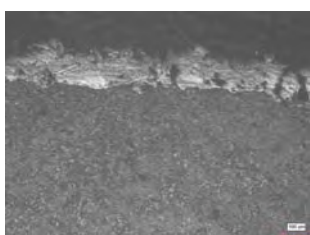
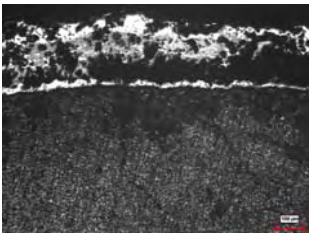
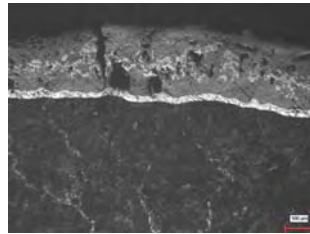
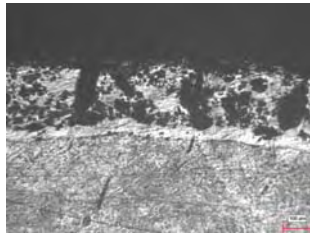
Diffusion parameters	Dip time	1 min	3 min	5 min
				
Temperature / Time		873 K / 2 hours	873 K / 5 hours	873 K / 8 hours
				
Temperature / Time		1023 K / 5 hours	1023 K / 8 hours	1023 K / 2 hours
				
Temperature / Time		1173 K / 8 hours	1173 K / 2 hours	1173 K / 5 hours

Figure 3. Microstructure of aluminized and diffused specimens with varying process parameters

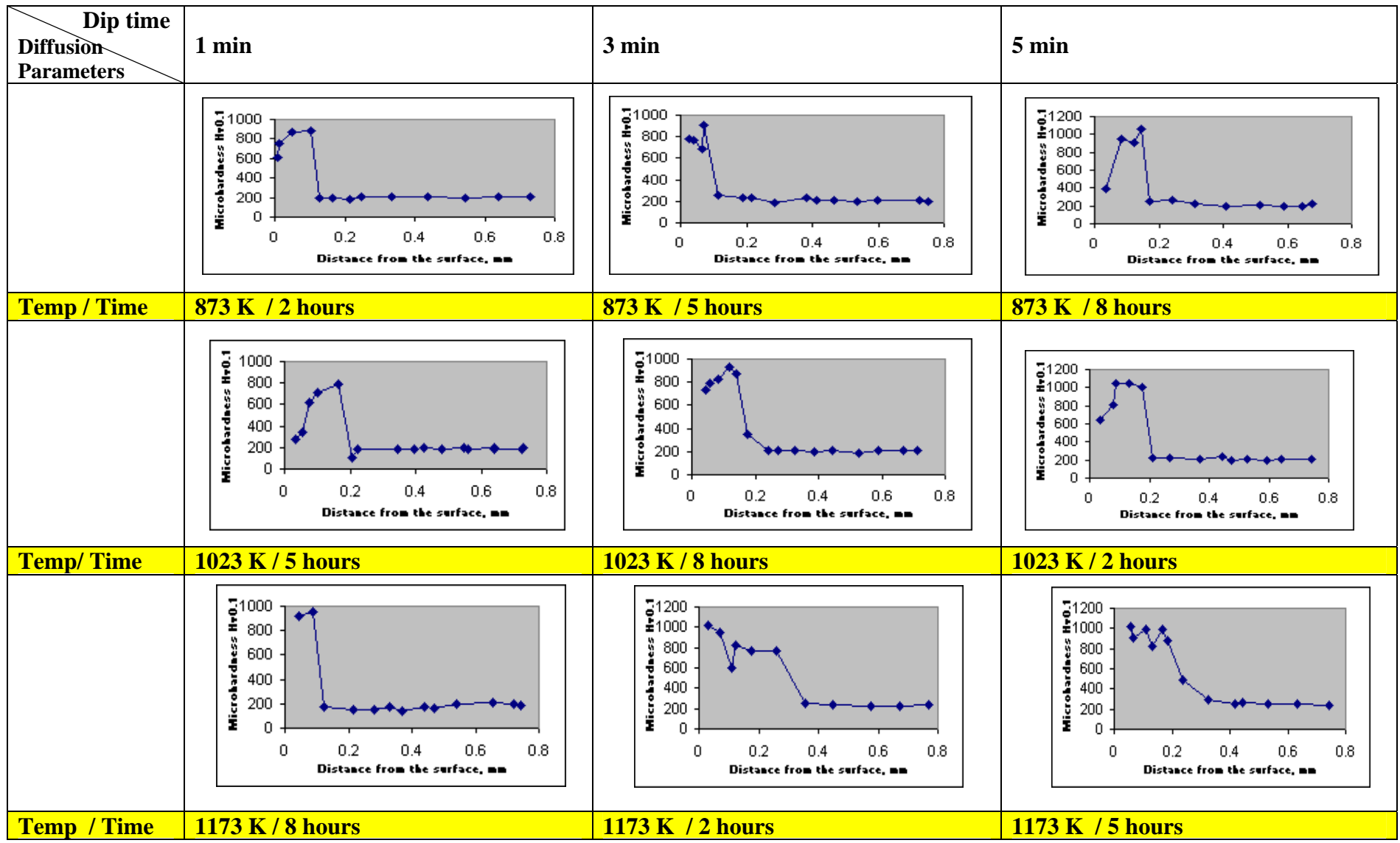


Figure 4. Microhardness traverses of aluminized and diffused specimens with varying process parameters

during aluminizing and formation of iron-aluminium complex layer during diffusion (9). The lower dip time (1 min) specimens yielded the increased hardness at the near surfaces whereas the high dip time extended its increased hardness towards the core material. The specimen dipped for 3 and 5 minutes showed the increased hardness (case depth of about 200 μm) from the surface. However, at high temperature diffusion treatments (1173 K) the surface showed the porous structure, probably arise from the oxidation. At higher diffusion temperature of 1173 K, the case depth was found to be high due to the porous layer. At lower diffusion temperature (1023 K), the case depth was around 170-190 μm with less porous layer. The specimens diffused at 873 and 1023 K may be chosen as a diffusion temperature and 3 min as a dip time, considering a non-porous surface and the increased case depth.

X-RAY DIFFRACTION STUDIES

X-Ray diffraction (XRD) studies were performed on the outer layer of aluminized and diffused specimens. The XRD characteristics of the aluminized and diffused specimen using Cu-K α are shown in Figure 5.

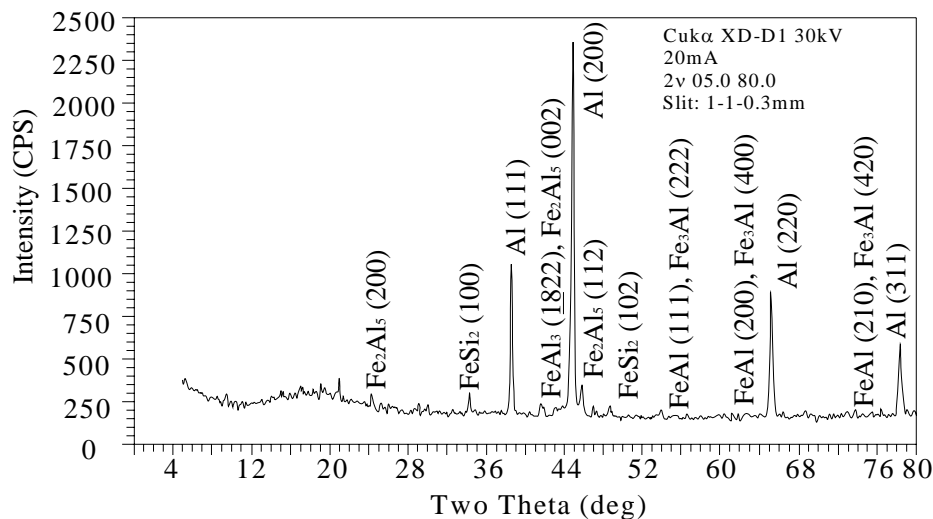


Figure 5. XRD characteristics of Aluminized & diffused specimen using Cu-K α radiation

The diffraction patterns of these specimens show that Fe₃Al, Fe₂Al₅, FeAl, FeAl₃ intermetallic phases are present in these coatings. Thus, the increased hardness in aluminized and diffused samples would be due to the presence of iron aluminides in the layer. These results are consistent with the literature (10).

CONCLUSION - Based on this study the following conclusions can be arrived at:

- i. Considering a non-porous surface and the increased case depth, the dip time of 3 min and diffusion temperature of 1023 K seems to be the optimum condition. However, higher diffusion temperature yielded porous surface and lower dip time showed a thin layer of case depth.
- ii. The hardness of EN 8 steel could be increased to a maximum of 1000 HV_{0.1} when aluminized and diffused.
- iii. X-Ray diffraction studies have confirmed the presence of aluminides in the alloy layer, which could be instrumental in the significant increase of surface hardness in steels, when aluminized.

Hence, aluminizing could be employed as a useful technique to improve the surface characteristics of steel components.

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