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Chromium-Aluminide Coatings on Inconel 718 Alloy and Fe-Cr-Ni SuperAlloy

Tuba YENER *

Abstract

In this study, it is invastigated the low-temperature chromium aluminide coatings on a FeCrNi-base superalloy and Inconel 718 by pack cementation method. Pack-aluminizing diffusion coating was applied at 800°C during 4 and 6 hours. The chromium-aluminising powder packs were prepared using aluminium and chromium powders as a source for depositing aluminium and chrominium, Al_2O_3 powder as an inert filler and ammonium chloride NH_4Cl as an activator. SEM (scanning electron microscope) EDS with energy dispersive X-ray spectrometer and XRD were used to characterize the coating layers. SEM analysis revealed that coating layers were homogenous, compact and nonporous and there was a good bonding at the interface of the coating and matrix. Layer thickness variation was changed from 11 to 18 µm measured from the surface to the matrix. The hardness of the coating layer increased to 1000 HVN while the hardness of the matrix was 340 HVN with the increasing process time.

Keywords: Low Tempeture pack Aluminising, Chromising, layer thickness, hardness.

1. INTRODUCTION

Steel has a widespread use in many industrial areas including transportation and general engineering and construction. Galvanized steel is mainly used for corrosion protection on the industry in order to resist corrosion [1]. Hovewer, since it is a expensive method, research has focused on cheaper and more durable coatings. The pack cementation technique an alternative technique can be applied to form hard and protective aluminide coatings on alloy steels [2], [3].

The need for coatings to upgrade surface properties such as abrasion and corrosion resistance, friction, oxidation and is increasing day by day [4], [5]. To resist oxidation at elevated temperatures, many superalloy part, such as turbine blades and nozzle guiding fins, are generally of interest in the diffusion aluminide coatings [6]. The formation of the protective alumina scale (especially under cyclic loading conditions) during high temperature exposures is preferred due to the strong interdifusion between aluminide coatings and superalloy substrate [7], [8]. Various metals and alloys that produce single or multi-component metal diffusion coatings and composite layers are an important for protecting the components from oxidation, aqueous corrosion and corrosion at high temperature [9]. High

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temperature protective coatings for Ni-based superalloys widely used in aircraft engines and industrial gas turbines. It is necessary to increase working life in oxidizing and corrosion environments. The formation of the protective slow-growing α-alumina layer on the coating surface plays a key role in obtaining the necessary protection. Such coatings are obtained by coatings containing high concentrations of Al provided by aluminum-rich phases [3]. In this context, the Cr element which also forms a protective oxide can also be selected [10]. The diffusion aluminide coatings are usually formed by exposing the superalloy to an Al-rich gas medium at elevated temperatures to provide alpha diffusion to the substrate or to allow for diffusion of nickel from the substrate [3] .

Diffusion aluminising and chromising of iron and steel has been a subject of high interest in relatively early published journals [9]. In the present work, aluminium-chrominium coatings are applied on the two types of metallic alloys surface (Inconel 718 commercial alloy and the other one ise Fe-Cr-Ni super alloy). In addition this, it is aimed to form Al-Cr coatings by using pack cementation process at relatively lower temperatures

1.1. Materials and Experiments

The commercial Inconel 718 and Fe-Cr-Ni superalloys were used as a substrate for coating, and their compositions are listed in Table 1.

Table 1. Chemical composition of Inconel 718 alloy and Fe-Cr-Ni super alloy

Element (Wt. %)	Al	Cr	Fe	Co	Ni	Mo	Si
Inconel 718	1.8	22.2	1.18	11	54	9.6	-
Fe-Cr-Ni Superalloy	0.36	21.54	54.6	-	21.28	-	2.22

Substrate samples with the dimensions of 10 mm×10 mm×8 mm were utilized in this work. The samples were ground up to 800 grit SiC emery paper, washed with acetone, ultrasonically cleaned in ethanol for 10 min and dried. 20 g of powder mixture containing 20% metallic Al, 10% metallic Cr, 5% NH_4Cl, 65% Al_2O_3 was used. Chloride salts commonly used for package cementation; NH_4Cl, NaCl and $AlCl_3$ [11]. The salt considered for this article is NH_4Cl. For an appropriate pack cementation operation, the amount of halide activator controlled in the range of 1% to 5% [11]. Thus, the addition of halide salts in the packages was chosen to be 5% by weight.

In pack aluminising process, the substrates were immersed in pack powders charged into a alumina crucible, which was covered with alumina powder over the lid was closed. The pack was then loaded into an open atmosphere furnace. The aluminising process temperature were applied at 800°C for 4 and 6 hours for both of the alloys. The microstructure and chemical composition of the cross-section of the coated specimens were analysed using scanning electron microscopy (SEM, Model JEOL JSM-6060, Japan) with energy dispersive spectroscopy (EDS). X-Ray diffraction (XRD, Model D/MAX-B/2200/PC, Rigaku Co., Japan) was used to identify phases formed in the surface layer of as-coated specimens with a wavelength of 1.5418 A Cu-Kα source radiation over a 2θ range of 10–80º. The micro-hardness of the test materials was measured using by a Vickers indentation technique with a diamond indenter a load of 0.98 N using Leica WMHT-Mod model Vickers hardness instrument. Hardness was measured along the cross sections of the samples and measurements were obtained using a 10-s holding duration. The hardness results were obtained by taking the average of 5 values.

2. RESULTS AND DISCUSSION

2.1. SEM-EDS Analyses

SEM micrographs of cross sectioned Inconel 718 and Fe-Cr-Ni super alloy aluminised and chromised at 800°C for 4 and 6 hours are given in Figure 1.It was observed that crominium-aluminide layer is dense, compact and it is silvery metallic appearance. Furthermore, when compared to the inconel 718, it is seen that the coating interface on the super alloy is layered but the inconel has a flat interface. The cracks in the outermost layer are formed during grinding and polishing, showing the brittleness of the aluminide layer [12]. The average layer thickness obtained is approximately the same both of the inconel and super alloy, in addition, it is seen that the coating interfaces are quite smooth for Inconel 718 alloy.

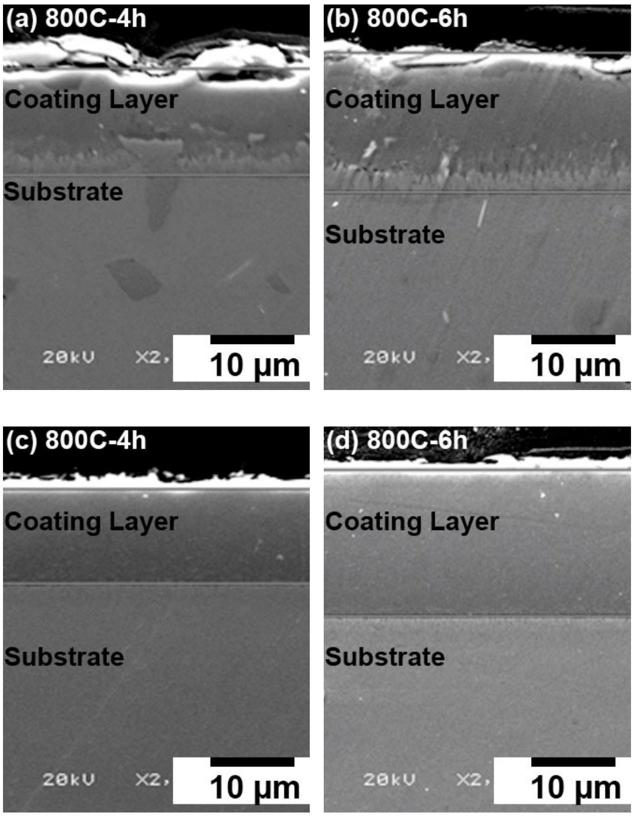


Figure 1. SEM Micrographs of Fe-Cr-Ni super alloy chrominium-aluminized at 800°C (a) 2h, (b) 4h and Inconel 718 alloy 800 °C (c) 2h, (d) 4h.

For further analysis of aluminide layer, the SEM-Map study was performed and they are given in Figure 2 and Figure 3. It is seen that the coatings deposited on the super alloy is more brittle whereas Inconel 718 alloy remains much more intacted. This can be resulted from the differences in the intermetallics phases formed on the coating. Another result that may be associated with this can be the hardness values of the coating.

Looking at SEM-MAP (Figure 2, Figure 3) analyses; at the coating surface, chromium deposition is more intense in the super alloy based coating. This is also supported by EDS analysis in Figure 4. Diffusion zone intensively contains Cr in the aluminised-chromised super alloy in Figure 2. Whereas in Figure 3 almost no interface (transition zone) can be existed in Inconel 718 alloy.

2.2. Hardness and Layer Thickness

The microhardness measurements, at 400 µm depth from surface are shown in Figure 5. The hardness of aluminide layer is much higher than that of substrate due to the formation intermetallic phases. Especially, higher aluminisation temperatures cause higher hardness because of formation of fully dense and thicker aluminide coating layer [12]. Hovewer chromium can increase the hardness and britleness of the aluminide layer thanks to the presence of interstiatil compounds such as Al_8Cr in the surface layer as it can be seen from XRD analyses (Figure 7).

When the hardness values and the layer thickness graphs (Figure 5) obtained from coating surface toward the center are taken into consideration; it is evident that the hardness and the layer thickness increased with processing time and temperature as it can be seen in Figure 6. With the formation of the coating layer, a high hardness increment at 800°C-6h was reached to about 1000 HV for Inconel 718 and 900 HV for super alloy. This can be attributed to formation of the intermetallics such as Ni_2Al_3, Al_8Cr_5 coatings during the pack aluminising process.

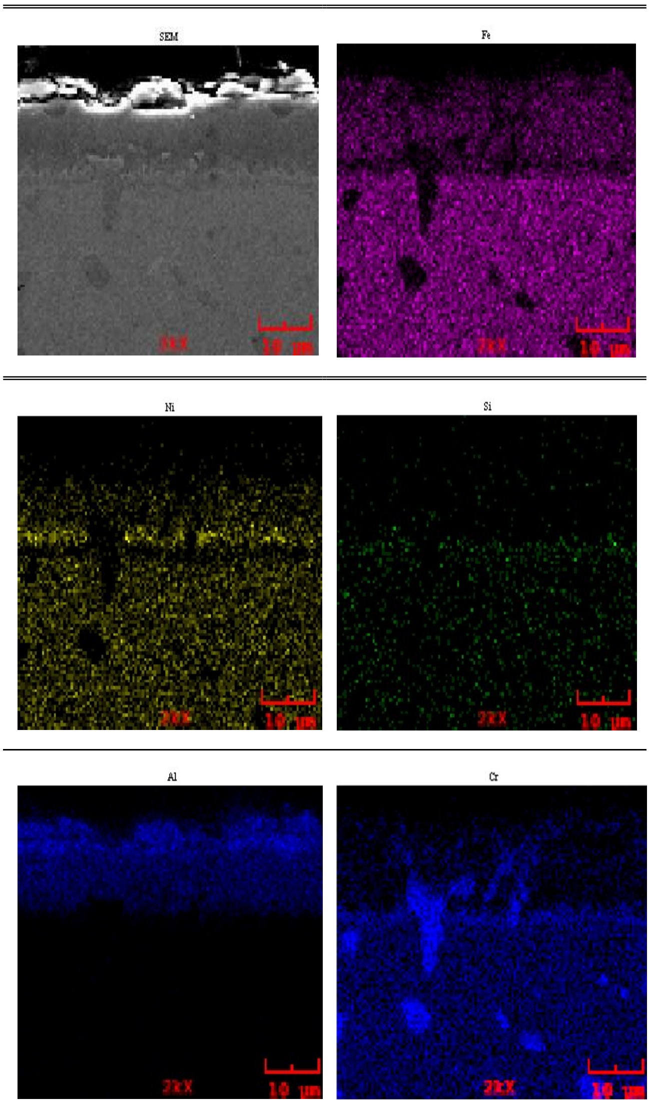
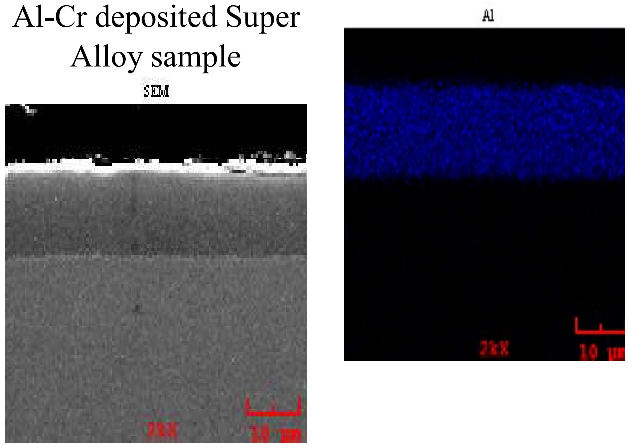


Figure 2. SEM-MAP analyses of 800°C-6h, Al-Cr deposited Super Alloy sample



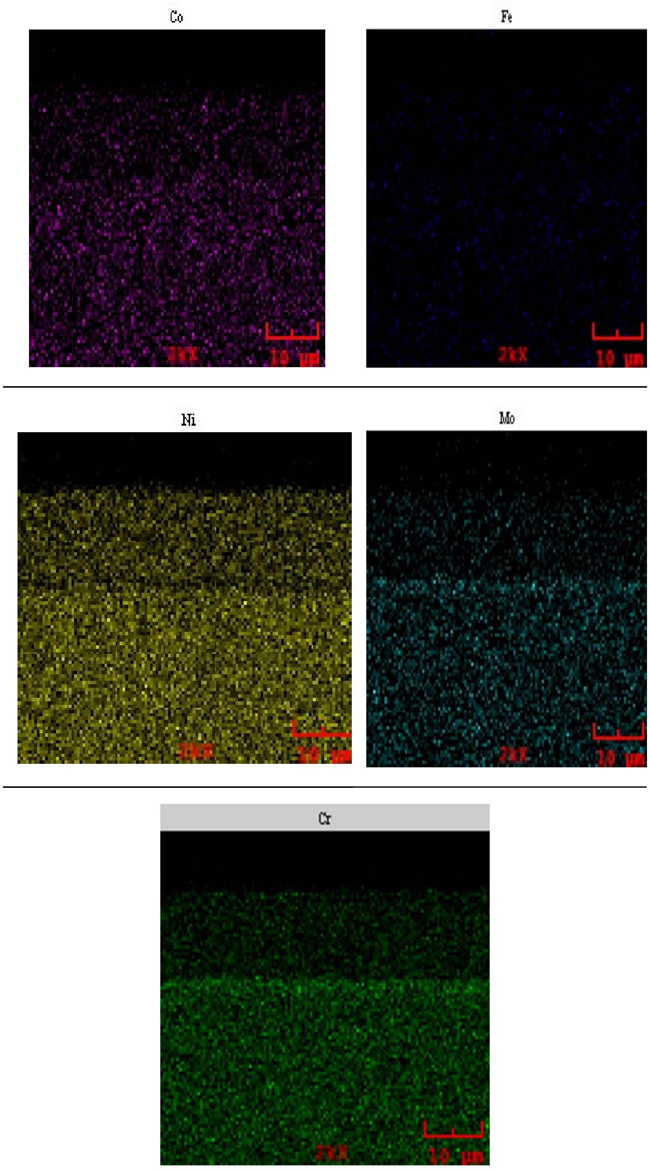
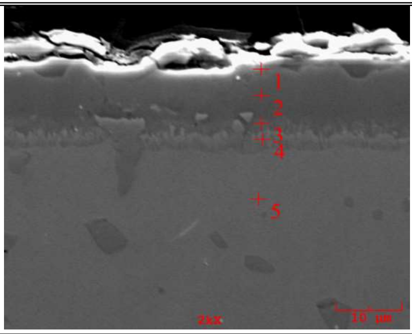
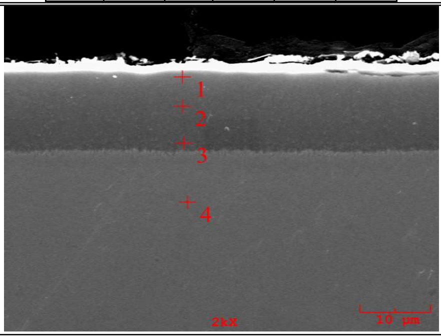


Figure 3. SEM-MAP analyses of 800°C-6h, Al-Cr deposited Inconel 718 sample.



(a) Fe-Cr-Ni Super alloy

	(wt%)				
Point	Al	Si	Cr	Fe	Ni
1	45,30		18,65	29,51	4,57
2	41,62		8,27	36,46	13,65
3	36,52		6,33	23,84	33,31
4	4,30	4,52	32,27	49,43	9,49
5		1,55	18,00	56,90	23,55



(b) Inconel Super Alloy

	(wt%)					
Point	Al	Cr	Fe	Co	Ni	Mo
1	44,62	11	1,43	5,28	33,69	3,99
2	42,50	11,80	0,87	6,2	32,81	5,82
3	38,58	12,83	0,97	6,05	37,08	4,50
4	2,57	23,71	1,65	10,46	53,76	7,86

Figure 4. SEM-EDS Analyses of 800°C-4h Al-Cr coatings.

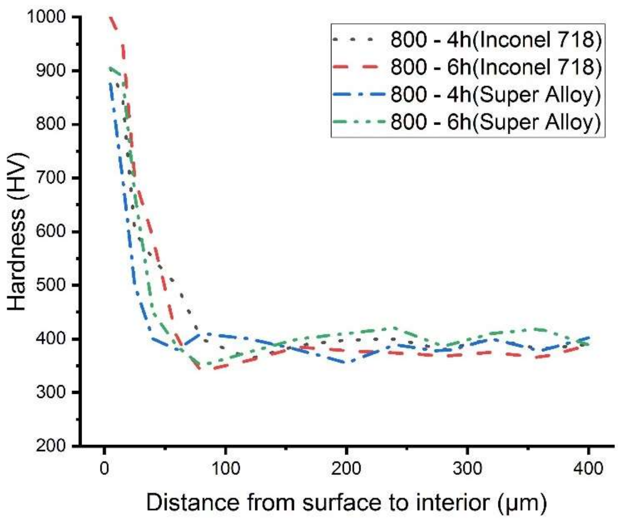


Figure 5. Hardness graphs of Inconel 718 and Super Alloy from surface to interior

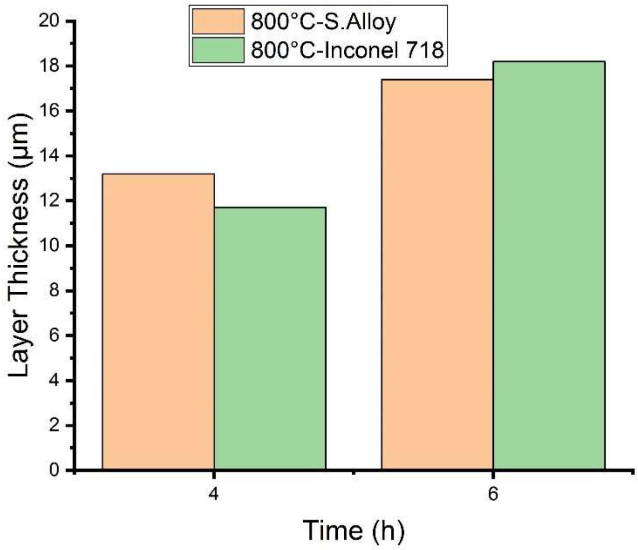


Figure 6. Variation of aluminizing layer thickness of Super alloy and Inconel 718 versus time

2.3. XRD Analyses

The results of the XRD analyses for both coating types are summarised in Figure 7. The XRD analyses confirms both the coatings were composed of aluminide phase. Compared with super alloy and inconel samples aluminised at 800°C-4h, the peaks of Inconel consist of Al_3Ni_2, AlFeMo, $AlCr_2$ where as Super alloy has Fe_3Al, Al_8Cr_5, $(SiAl)_2Cr$ phases.

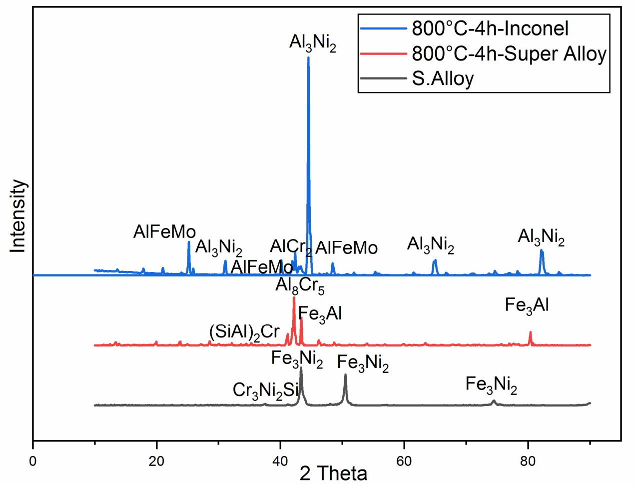


Figure 7. XRD Analyses of Inconel 718 and Super Alloy Samples Aluminised and Chromised at 800°C-4h

2.4. Conclusions

In this study Al-Cr coating on two type of super alloys has been studied at 800 °C for 4 and 6 hours in a powder pack containing 20% Al, 10% metallic Cr, 5% NH_4Cl, 65% Al_2O_3 using pack cementation method on a superalloy and Inconel 718 allloy. The following conclusions can be drawn from this work:

- Fully dense and uniform aluminide coating was obtained on the Fe-Cr-Ni and Inconel 718 type superalloy substrate. Almost no cracks, holes or other defects were observed in substrate/coating interface and inside the coating.
- 800°C -4 and 6 hours are sufficient for aluminide coating formation. According to XRD anayses; Inconel 718 alloy contains Al_3Ni_2, AlFeMo, $AlCr_2$ phases, where as super alloys coating has Fe_3Al, Al_8Cr_5, $(SiAl)_2Cr$ phases.
- Depending on the increase in the time, the coating layer increased from 13,2 µm to 17,4 µm for süper alloy and from 11,7 to 18,2 µm for Inconel 718.
- Hardness values of coating layer formed on the surface of aluminised super alloy measured as 900 and 1000 HV respectively for Fe-Cr-Ni Super alloy and Inconel 718 at 800°C for 6h whereas hardness of matrix is at about 350 HV.

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