Indian Journal of Chemical Technology
Vol. 26, May 2019, pp. 244-247

Low temperature aluminising of Inconel 718 alloy by pack cementation(ICCESEN 2017)

Tuba Yener*[,1], Gözde Ç Efe[1,2] , Mediha İpek[1] & Sakin Zeytin[1]

[1]Sakarya University, Metallurgy and Materials Department, Adapazar, Turkey.

[2]Sakarya University, Biomedical, Magnetic and Semi-conductive Materials Research Center (BIMAS- RC), Sakarya, Turkey.

E-mail: tcerezci@sakarya.edu.tr

Received 20 February 2019; accepted 25 March 2019

A novel pack-aluminizing diffusion coating has been conducted on –Inconel 718 alloy at 600 and 650°C for 2 and 4 h. The aluminising powder packs have been prepared using Al powder as a source for depositing aluminium, Al_2O_3 powder as an inert filler and ammonium chloride NH_4Cl as an activator. The microstructures of the coatings formed on the alloy surface are characterized by means of SEM/EDS and XRD analysis. Optical microscope and SEM analysis reveal that coating layers are homogenous, compact and nonporous and there is a good bonding at the interface of the coating and matrix. Layer thickness variation is measured from the surface to the matrix and changed from 10 to 40 µm which is increased with increasing process time and temperature. The hardness of the coating layer increased to 1174 HVN with the increasing process time and the temperature while the hardness of the matrix is 300 HVN.

Keywords: Packaluminising, Layer thickness, Hardness

Inconel 718 is a essentially nickel-based, precipitate hardening superalloy[1]. Materials with high strength and high temperature resistance, especially nickel-based alloys and titanium alloys, have found widespread use in recent years[2]. Nickel based alloys are known as an alloy capable of maintaining high temperature strength, and its superior mechanical properties at high temperatures make it one of the most preferred materials for engine discs, blades and drive-shafts in the aircraft engine turbine applications[1,3,4]. However, the relatively weak tribological properties, particularly the low hardness and poor wear resistance, limit the use in many applications. For this reason, the development of innovative surface modification processes that enhance the surface hardness of Inconel 718 is of technological importance[1]. Different methods have been used to produce an aluminide layer on the surface of these alloys. These methods include pack aluminizing, magnetron sputtering, hot dipping, PVD, etc.[5]. Thermochemical surface treatments such as pack cementation or pack aluminising have proved to be an effective technique because aluminide diffusion coatings on steel or other metal alloy types deposits as a homogeneous layer[6]. Pack cementation is one of the industrially applied aluminising methods for coating Ni-based and Ti-based alloys[7-10]. Aluminising is widely used as a coating method for conventional steels and heat resistant alloys. This method is low cost and has the advantage of forming a simple oxidation-resistant aluminide layer with reaction diffusion on a substrate[11]. The pack cementation process can be applied to form aluminide coatings on alloy steels. This process has the processing simplicity and flexibility required to process the components of various sizes and geometries. However, a restriction of the process is that it requires thermal activation to produce sufficiently fast chemical reactions and interdiffusion kinetics. The process in this way is normally carried out at temperatures above 750°C. At these temperatures it may result in degradation mechanical properties of alloyed steels, such as grain coarsening and carbide precipitation. To prevent this deterioration, aluminising should be carried out at temperatures below 700°C[12]. The present study is thus undertaken to investigate the effects of deposition conditions for Inconel 718 alloy at temperatures 600 and 650°C for 2 and 4 h. During this process, the aluminium deposited onto the component surface from the vapour phase reacts with nickel to form intermetallics (aluminide).

Experimental Section

Inconel 718 was used as an experimental material in this study. The nominal composition of Inconel 718 is as seen in Table 1.

Substrate samples with the dimensions of 10 mm × 10 mm × 8 mm were prepared and used in this work. The samples were ground up to 1000 grit SiCemery paper, washed with acetone, ultrasonically cleaned in ethanol for 5 min and dried. 100 g of powder mixture containing 10% metallic Al, 5% NH_4Cl, 85% Al_2O_3 was used as a chloride-gas-generating source. In pack aluminising process, the substrates were buried in pack powders charged into a cylindrical alumina crucible, which was then sealed with an alumina lid. The pack was then loaded into an open atmosphere furnace. The aluminising process temperature were applied as 600 and 650°C for 2 and 4 h. 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., Ja- pan) was used to identify phases formed in the surface layer of as-coated specimens with a wavelength of 1.5418 A over a 2θ range of 10–80º C with Cu-Kα source radiation. The thickness of the aluminised layer was estimated from element concentration depth profiles measured by EDS. 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.

Results and Discussion

SEM micrographs of cross sections Inconel 718 alloy aluminised at 600 and 650°C for 2 and 4 h are given in Fig 1.

It is obvious that the coating layer increases in proportion with the increase in temperature and time. It was observed that aluminide layer is dense, compact and is of silvery metallic appearance. Additionally, matrix and coating interface is quite smooth whereas aluminide coatings exhibit rough surface with a single layer structure. The cracks in the outermost layer are formed during grinding and polishing, indicating the fragility of the aluminide layer[6]. For further analysis of aluminide layer, the SEM-Map study was performed and they are given in Fig. 2

Table 1 — Chemical composition of Inconel 718 alloy

Element (Wt. %)	Al	Cr	Fe	Co	Ni	Mo
Inconel 718	1.8	22.2	1.18	11	54	9.6

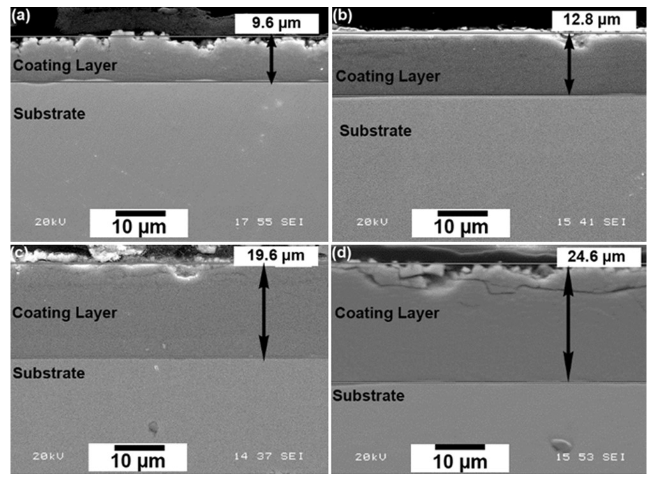


Fig. 1 — SEM Micrographs of aluminized Inconel 718 alloy at 600°C (a) 2h, (b) 4h and 650°C (c) 2h, (d) 4h

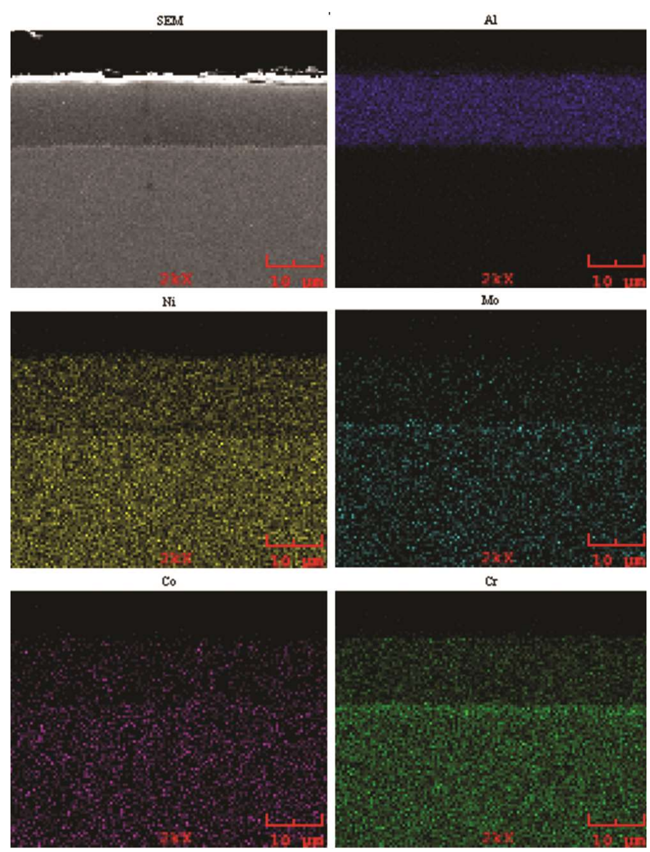
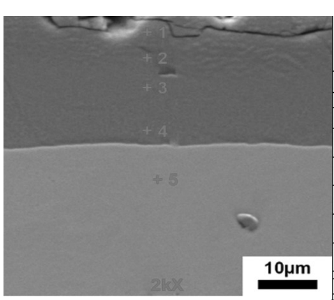


Fig. 2 — SEM-MAP analysis of Inconel 718 alloy pack aluminized at 600°C for 4 h

As it can be seen in SEM-elementel x-ray mapping analyses illustrated in Fig 2, aluminium and nickel were deposited intensively in the coating layer. SEM-EDS analyses also support this results and EDS analyses showed that nickel aluminide phase formation occurred on the top of Inconel 718 alloy. In order to verify the accuracy of the analysis results, XRD was used to detect the phases in the coating. Besides the major aluminide phase in the surface layer detected by XRD was NiAl, also some molybdenum aluminide has identified in the coating layer.

According to the results of EDS analysis,given in Fig 3, the coating layer consists of Al, Ni Cr, Mo and Co phases. There is not any porosity between the coating layer and the matrix. The crack which are seen on the top of the layer islikely to occur during grinding and polishing.

Fig 4(a), plots the coating thickness as a function of time and temperature. It shows that the coating thickness increased progressively from approximately 9.3 to 25.6 µm with increasing time and process temperature. The hardness variation versus to the distance from surface to interior as it can be seen in Fig 4(b), the highest hardness value of 650°C was obtained as a result of 4 h of aluminising process and it reached a hardness value of 1174 HV. Similar to the increase in the coating layer, time and temperature are also effective in increasing the hardness. Whereas the matrix hardness is about 300 HV, the hardness reaches to 710 HV on coating layer even at the end of 2 h at 600°C which is the lowest temperature application. The temperature ensures that the coating layer is deposited in a dense form. Such high hardness is expected to be favourable for wear-resistance applications[8,13]. This hardness can be attributed to fine-aluminide precipitates present in the structure and also phases detected by XRD analysis (Fig 5).



Marks

Elt.	1	2	3	4	5
	Wt (%)				
Al	66,72	62,08	59,05	57,64	2,13
Cr	8,71	9,65	8,97	10,28	22,97
Fe	0,91	0,96	0,63	0,83	1,98
Co	3,85	4,10	4,53	4,91	10,88
Ni	15,04	17,68	22,01	20,34	52,79
Mo	4,78	5,52	4,81	5,99	9,26

Fig. 3 — SEM-EDS analysis of Inconel alloy pack aluminized at 650°C for 4 h.

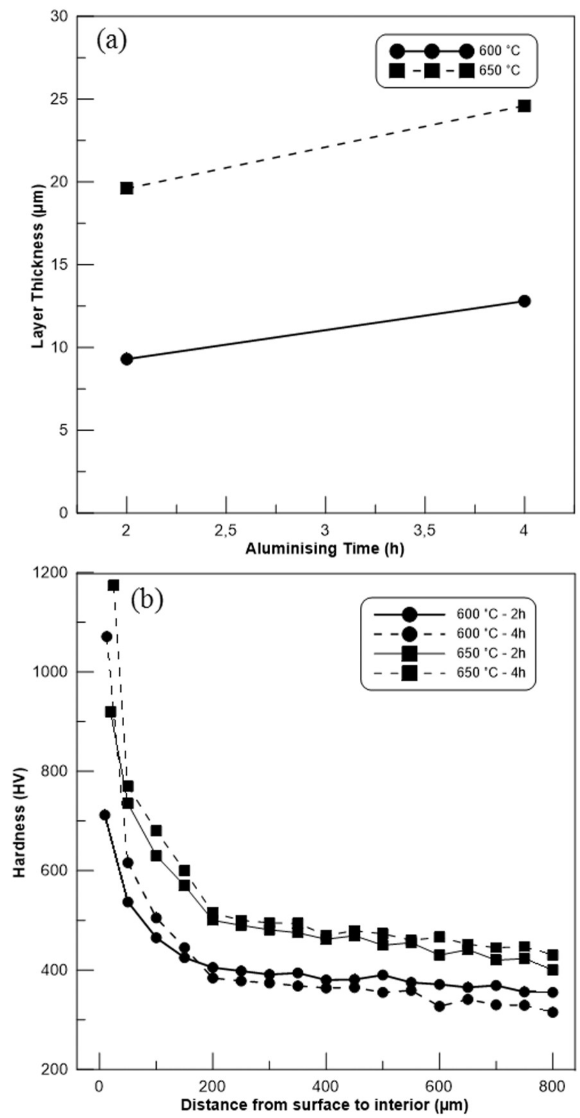


Fig. 4 — Variation of (a) aluminising layer thickness versus aluminising time, (b) hardness versus distance from surface to interior for pack aluminised Inconel 718 alloy

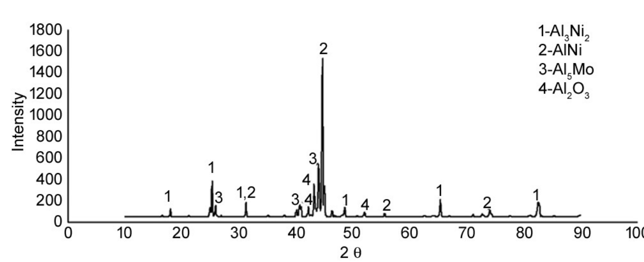


Fig. 5 — XRD analysis of Inconel 718 alloy pack aluminized at 650°C for 4 h.

Conclusion

In this paper, low temperature aluminising process has been applied to Inconel 718 alloy at 600 and 650°C for 2 and 4 h. The following conclusions can be drawn from this work:

- Low temperatures (600 and 650°C) are sufficient for aluminide coating formation. The phases are detected as NiAl, Ni_2Al_3, $MoAl_5$ and Al_2O_3. Fully dense and uniform aluminide coating is obtained on the Inconel 718 substrate. No cracks, holes or other defects are observed inside the coating.
- Depending on the increase in temperature and time, the coating layer also increased from 9,6 μm to 24,6 μm.
- Hardness values of coating layer formed on the surface of aluminised Inconel alloy measured as 1174 HV at 650°C for 4h whereas hardness of matrix is about 300 HV. The lowest hardness result of 300 HV is obtained at 600°C-2h aluminised sample.

Acknowledgement

The authors thank expert Fuat Kayis and Murat Kazanci for performing XRD and SEM-EDS studies and special appreciation is expressed to technicians Ersan Demir and Erkut Tas, and Emir Demiröz, Yunus Bayrak, Diyar Aytek of Sakarya University for assisting with experimental studies.

References

1 Zhang H, Qin H, Ren Z, Zhao J, Hou X, Doll G L, Dong Y & Ye C, *Surf Coat Technol*, 330 (2017) 10.
2 Karimi Zarchi, H R, Soltanieh M, Aboutalebi M R & Guo, *Trans Nonferrous Met Soc China*, 23 (2013) 1838.
3 Pan Z, Feng Y, Hung T-P, Jiang Y-C, Hsu F-C, Wu L-T, Lin C-F, Lu Y-C & Liang S Y, *J Manuf Process*, 30 (2017) 141.
4 Kakehi K, Latief F H & Sato T, *Mater Sci Eng A*, 604 (2014) 148.
5 Sun Y, Dong J, Zhao P & Dou B, *Surf Coat Technol*, 330 (2017) 234.
6 Xiang Z D & Datta P K, *Surf Coat Technol*, 184 (2004) 108.
7 Abakay E, Durmaz M, Sen S & Sen U, *Acta Phys Pol A*, 132 (2017) 682.
8 Celebi Efe G, İpek M, Bindal C & Zeytin S, *Acta Phys Pol A*, 132 (2017) 760.
9 Altinsoy İ, Çelebı Efe G F, Yener T, Önder KG & Bındal C, *Acta Phys Pol A*, 132 (2017) 663.
10 Wang J, Wu D J, Zhu C Y & Xiang Z D, *Surf Coat Technol*, 236 (2013) 135.
11 Sasaki T, Yagi T, Watanabe T & Yanagisawa A, *Surf Coat Technol*, (2011).
12 Xiang Z D & Datta P K, *Acta Mater*, 54 (2006) 4453.
13 Günen A, *Acta Phys Pol A*, 130 (2016) 217.
14 Erdugdn A, *Surf Coat Technol*, 357 (2019)886.
15 Crok M S, A Erdogan, M Oge & A Giinen, *Surf Coat Technol*, 328 (2017) 54.