VOL. 11, NO. 24, DECEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

FEASIBLE JOINING ON THE REACTION LAYER OF DIFFUSION BONDED SIALON AND DUPLEX STAINLESS STEEL

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ABSTRACT

The main objective of this work is to analyse the feasible joining in microstructure and the interdiffusion of elements on the reaction layer of diffusion bonded sialon with duplex stainless steel. Combination of these two materials is a complex task due to dissimilar in thermal expansion coefficient. Diffusion bonding of sialon and duplex stainless steel was conducted by applying pressure of 16 MPa at 1200 °C for 30 minutes and 1 hour in a vacuum hot press furnace. The reaction layer that connected sialon and duplex stainless steel was analysed using optical microscopy and scanning electron microscope for its microstructure while energy dispersive x-ray was used for elemental diffusion analysis. The samples of 30 minutes and 1 hour diffusion bonding time show good joining were attained due to ductile layer. Formation of pearlite near to the steel was also revealed in both samples. Small gaps can be discovered on the reaction layer in 30 minutes diffusion bonding time as compared to 1 hour. However, the joining on both samples remained intact due to presence of reaction layer.

Keywords: duplex stainless steel, diffusion bonding, elemental, microstructure and sialon.

INTRODUCTION

Sialon ceramics is derived from silicon nitride by adding sintering additives such as MgO and Y_2O_3 [1, 2]. The high toughness, resistance towards corrosion, high temperature and wear made this material to be favourable in petrochemical industries and various industrial wear parts. Although it possessed some good qualities that seek by industries, due to its brittleness, the usage is very limited. Duplex stainless steel on the other hand, has high tensile strength and able to withstand corrosive environment. However, the strength tends to weaken as the temperature increases.

Joining of sialon and duplex stainless steel could overcome the weaknesses of these two materials. Based on Nicholas [3], permanent joining of similar and dissimilar materials comprises of several processes. The five main processes are fusion welding, brazing, glazing, adhesive bonding and diffusion bonding. The most well-liked joining process would be metal brazing. Nevertheless, metal brazing has its limitation which the ceiling limit temperature is only up to 400 °C [4, 5]. Hence, metal brazing is not suitable for high temperature application. Diffusion bonding is the only process that requires no localized melting of foreign materials as compared to the others [3]. The solid state process creates an interface diffusion that would bond the two materials together but combination of these materials is highly complicated due to different in thermal expansion coefficient.

Few works were reported on the joining of sialon and stainless steel via diffusion bonding. Joining of sialon with austenitic stainless steel produced crack due to absent of ductile layer on the reaction layer [6]. Ferritic and martensitic stainless steel on the hand had shown a very promising result of bonding with sialon which formed a ductile reaction layer on the joined materials [2, 6, 7, and 8].

Duplex stainless steel is a unique type of stainless steel which contains two phases of microstructure – austenite and ferrite. However, joining of sialon to duplex stainless steel is yet to be attempted. Therefore, in this work, it is aimed to analyse a feasible joining of a solid state diffusion bonded sialon and duplex stainless steel on the reaction layer by studying the microstructure and elemental diffusion at two different diffusion bonding time of 30 minutes and 1 hour.

MATERIALS AND METHODS

Materials

The 201 β-sialon was provided by International Syalons (Newcastle) Ltd. UK with dimension of 20 mm diameter and 4 mm thickness. 2205 duplex stainless steel (E Steel Sdn Bhd) was used to join with the sialon. The 20 mm diameter rod of duplex stainless steel was cut into a thickness of 1.5 mm using electrical discharge machining (EDM) wire cut. The both sides of coin-like duplex stainless steel was then ground and polished to a mirror finish. After that, the steel sample was rinsed with acetone before underwent diffusion bonding.

Diffusion bonding

The sample was arranged in a sandwich form which the duplex stainless steel in between of two sialons. The diffusion bonding was conducted using the Nisshin Giken vacuum hot press furnace as shown in the schematic diagram in Figure-1. The inner part of the graphite components was covered with boron nitride to avoid reaction with the samples. The process was carried out by heating up to 1200 °C in a vacuum condition of 3.6 x 10^{-6} Torr at a heating rate of 5 °C/min. Then, a uniaxial pressure of 16 MPa was applied for a dwelling time of one hour. After dwelling, the pressure was released slowly and the sample was cooled down to 700 °C at a cooling rate of

5°C/min. After that, the sample was left to cool down in the furnace till room temperature.

Characterization

After joining, the sample was cut into half using the diamond cutter to obtain its cross-section. Then, the sample was ground using diamond abrasive paper and polished using alumina paste of 5 µm. Kalling's No 2 etchant was used to reveal its microstructure. Leica DMLM optical microscope and Zeiss Supra 55 scanning electron microscope (SEM) were used to analyse the microstructure of the joined sample. Electron dispersive X-ray (EDX) which attached to the SEM was used to identify the elements that diffuse throughout the reaction layer.

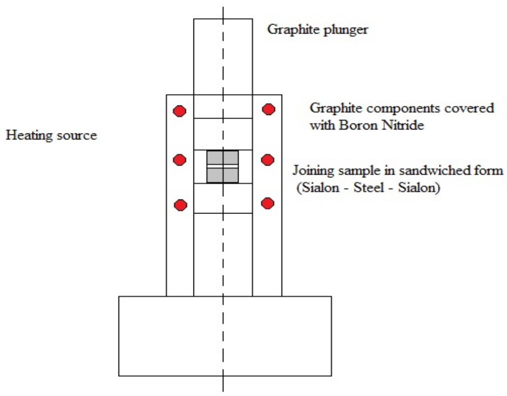


Figure-1. Schematic diagram of diffusion bonding process.

RESULTS AND DISCUSSIONS

Microstructure analysis

Microstructure analysis plays an important role in understanding the structural elements and defects that may influence the properties of materials [9]. Four noticeable layers namely sialon, interface layer, diffusion layer and parent steel can be observed in Figure-2a and Figure- 2b. Combination of diffusion layer and reaction layer is called a reaction layer [8, 10].

Joining of sialon with duplex stainless steel for 30 minutes produced gaps along the interface layer. However, the gaps appeared to be smaller around 8.75 µm of thickness in Figure- 2c. This is supported with the joined sample remained intact after it was break into half. On the other hand, diffusion bonding for 1 hour provides better ductile layer as compared to 30 minutes. A clearer image on the interface and diffusion layer can be observed on the scanning electron micrograph as in Figure- 2d. The formation of gaps could be due to insufficient of time for the materials to be thoroughly in contact [8]. As reported by Sozhamannan [11], at constant temperature the strength of the joint increases with longer holding time that caused by the interdiffusion of elements.

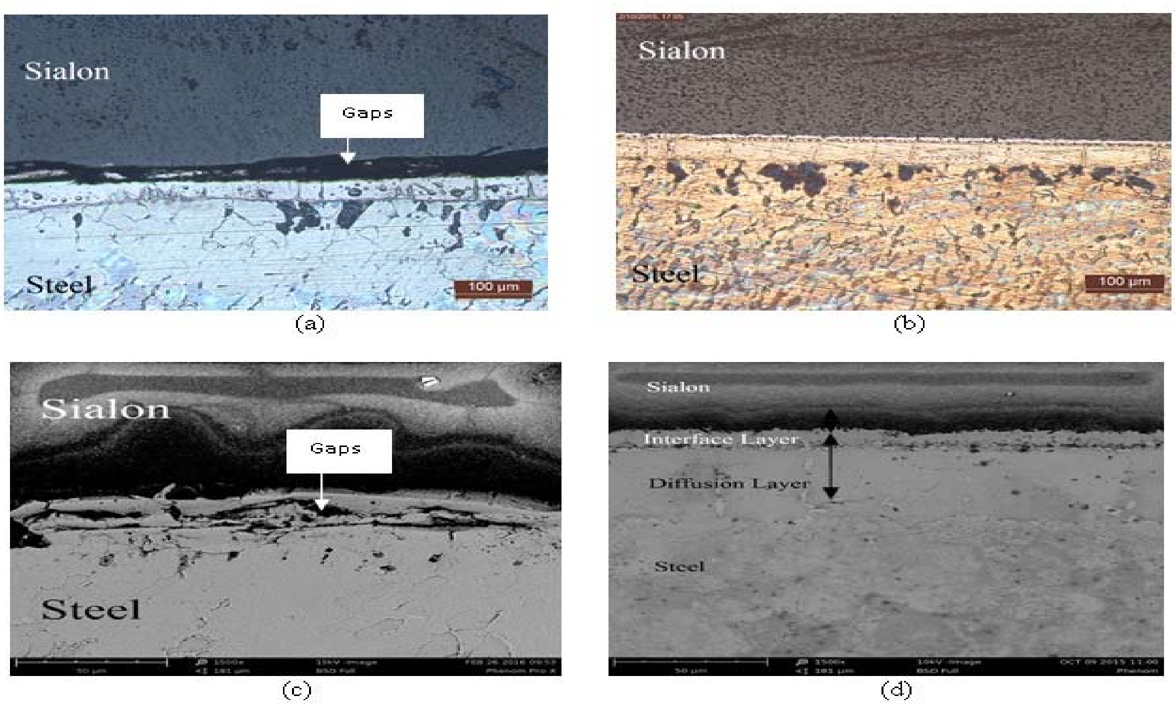


Figure-2. Optical micrograph of the joint for bonding time of: (a) 30 min and (b) 1h; Scanning electron micrograph of the joint for bonding time of: (c) 30 min and (d) 1h.

The average thickness of interface and diffusion layer for 30 minutes diffusion bonding time was 10.2 µm and 31.0 µm. However, for 1 hour diffusion bonding time sample, the average thickness was slightly higher due to longer time which was 11.8 µm and 44.3 µm respectively. The diffusion layer is found to be thicker as compared to interface layer for both samples. This is due to the atomic diffusion of elements between sialon and duplex stainless steel. Duplex stainless steel contained two different structure of face-centered cubic (FCC) and body-centered cubic (FCC). On the contrary, sialon has a complex tetrahedral Si-N structure which is much harder for the elements to diffuse [12]. Therefore, the elements tend to disseminate towards the stainless steel rather than the sialon.

Formation of pearlite can also be discovered near to the steel for both samples as in Figure- 3. The pearlite is suspected to be nitrogen pearlite as reported by Hussain [13], which was the result of interdiffusion from sialon with austenitic stainless steel. Pearlite consists ferrite phase – light layer, and cementite phase which mostly appears as dark lamellae. Callister [9] mentioned that the mechanical property of the pearlite is between the hard cementite and ductile ferrite. Thus, this formation of microstructure could be either give an advantage or vice versa to the joint of sialon and duplex stainless steel.

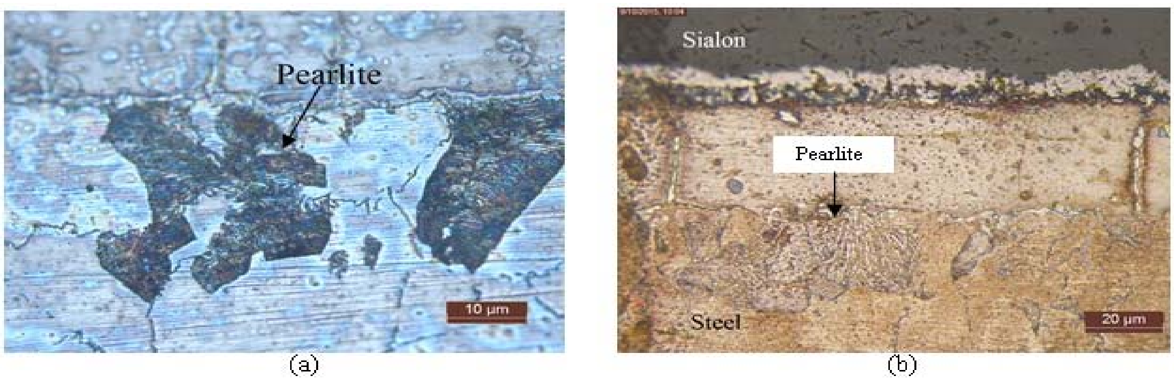


Figure-3. Optical micrograph for diffusion bonding time of (a) 30 minutes and (b) 1hour.

Elemental analysis

A study carried by Vleugels *et al* [14], has found that the chemical reactivity between sialon and iron based alloy started around 1030 °C -1070 °C. Since, the diffusion bonding temperature in this work was conducted at 1200 °C, therefore, elemental exchange at the interface and diffusion layer can be expected. EDX analysis has been performed to study the diffusion of elements.

Based on Figure-4 and Figure-5, the concentration of silicon, nitrogen, aluminum and oxygen were diminished from sialon to the duplex stainless steel and inversely, iron and chromium concentration depleted towards sialon. It was found that the concentration of silicon and nitrogen were much higher in the reaction layer rather than the sialon itself.

Vleugels [14] also stated that sialon dissociate silicon and nitrogen to diffuse with iron alloys while aluminium and oxygen combine to form Al_2O_3. The dissociation of silicon and nitrogen may results in silicides and nitrides formation at the reaction layer which is detrimental to the joined materials [10, 15]. However, the usage of EDX is limited to analyse the compound. Although the presence of silicides and nitrides at the reaction layer may be suspected on the reaction layer, the joined materials remained intact as the concentration did not exceed the critical limit and no crack was formed.

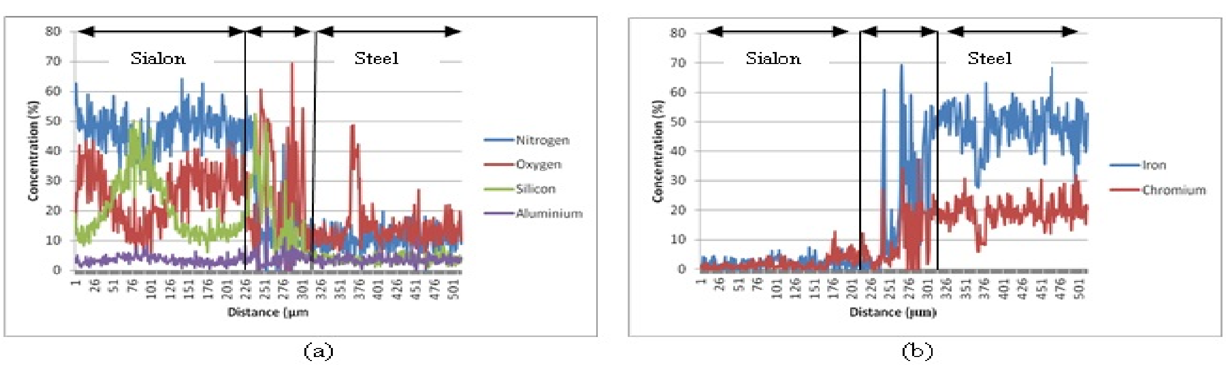
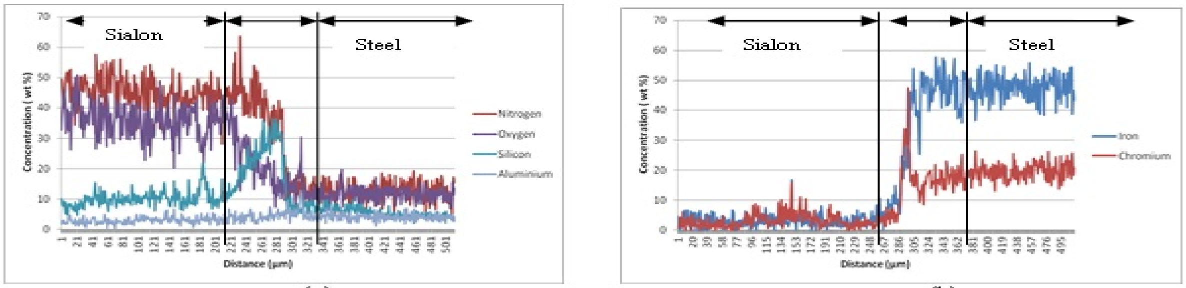


Figure-4. EDX for 30 minutes diffusion bonding time of (a) N, O, Si and Al; and (b) Fe and Cr.



(a) (b)

Figure-5. EDX for 1 hour diffusion bonding time of (a) N,O, Si and Al ;and (b) Fe and Cr.

CONCLUSIONS

In a nutshell, sialon is feasible to be diffusion bonded with duplex stainless steel. A reaction layer which consists of interface and diffusion layer was formed to accommodate the bonding at the surface intact. A longer diffusion bonding time of 1 hour produced better joining as compared to 30 minutes bonding time. Besides, nitrogen pearlite was observed near to the parent steel in both samples. High concentration of silicon and nitrogen was also found at the reaction layer for both samples which could lead to the formation of silicides and nitrides compound. The two compounds may result in failure to the joined sample for its brittleness. However, no crack is formed on the reaction layer.

ACKNOWLEDGEMENTS

The authors would like to thank Universiti Teknologi Petronas and SIRIM Shah Alam for providing the facilities and services. The work is funded by the Exploratory Research Grant Scheme (ERGS: 0153AB-I21) from Ministry of Higher Education (MOHE).

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