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INTERMETALLIC BONDING BETWEEN A RING CARRIER AND AN ALUMINUM PISTON ALLOY

Srećko Manasijević[1], Zdenka Zovko Brodarac[2], Natalija Dolić[2], Mile Djurdjević[3], Radomir Radiša

[1]Lola Institute Ltd, KnezaVišeslava 70a, Belgrade, Serbia
[2]University of Zagreb Faculty of Metallurgy, Alejanarodnihheroja 3,Sisak, Croatia
[3]Nemak Europe, Zeppelins Trasse 24, 4020 Linz, Österreich

Abstract
This paper presents an analysis of the intermetallic bond between a ring carrier and an aluminum piston alloy. An optical microscope combined with the SEM / EDS analysis has been used to metallographically analyze the quality of the intermetallic bonding layer. The obtained results show that can be established intermetallic bond between two materials of different qualities.

***Keywords**: piston alloys, ring carrier, intermetallic bond, Ni-Resist, Al-Fin process.*

1. INTRODUCTION

Pistons are made mostly of aluminum multicomponent alloys (Al−Si−Cu−Ni−Mg), which are used in the automotive industry due to a combination of good casting and mechanical properties [1−5] high strength at elevated temperatures (up to 350 °C) [1,2] and also resistance to sudden temperature changes [1,3−5]. Depending upon the engine type and operating conditions, there are different design solutions for pistons.

This paper deals with pistons for highly-loaded diesel engines with a ring carrier. The ring carrier is specially designed to form the first piston ring groove. The ring carriers of standard features are made of austenitic cast iron (Ni-Resist) in order to increase the wear-resistance of the first ring groove, especially in engines with high loads [5−9]. Austenitic gray iron castings are used primarily for their resistance to heat, corrosion, and wear, as well as controlled expansion, temperature stability, castability, and machinability. The Ni-Resist ring groove inserts are manufactured into pistons to increase engine and piston life. In the meantime, they can also improve the air-tightness of the piston in the cylinder, increase the efficiency of combustion, reduce emissions and air pollution, and contribute to the environment.

The alfin process is a method for preparing a ferrous surface for intermetallic bonding [5−9]. The alfin bonding process is commonly used to bond a non-ferrous Al alloy and a ferrous alloy. It is well known that cast iron contains carbon as a result of the casting process[5−9]. During the piston casting, the ring carrier is soaked by the alfin bond process, which results in a strong connection with the piston material. During this process, an intermetallic layer composed of Fe_xAl_y is formed on the border between the two different materials by the diffusion of atoms[5−9].

The aim of this paper is to conduct a detailed analysis of the intermetallic bonding layer that is formed between the ring carrier and the piston.

2. EXPERIMENTAL

The tests were performed on an Ø89 mm piston for a diesel engine. A cross-section of the investigated piston casting with its macrostructure and indicated sampling point is shown in

Figure 1a. The chemical compositions of the piston alloys and ring carrier given are in Table 1. In this case, the hardness of the ring carrier is 140−150 HBS (the standard is 120−160 HBS)[5].

Table 1. Chemical composition of the experimental alloy (wt. %).

Alloy	Element/chemical composition									
AlSi13Cu4Ni2Mg	Si	Cu	Ni	Mg	Fe	Mn	Cr	Ti	Zr	V	Al
	13.05	3.80	2.01	0.90	0.52	0.19	0.09	0.07	≈0.03	≈0.01	residual
Sample of the ring carrier	Ni	Cu	C	Cr	Si	Mn					Fe
	15.10	6.32	2.81	2.21	1.89	1.23					residual

The instruction for forming connections between the ring carrier and the piston casting is a trade secret of all producers.

The melting of the alloy for piston casting was performed in a tub-like electro-resistant furnace-type RIO 750 (80 kW and a melting capacity of 120 kg/h). The preparation of the Al-alloy was performed in an electro-resistant muffler-like furnace type RIO 250 (85 kW). During preparation, the piston casting was exposed to melt-treatment processes (refining, modification, and degasification at 725±5 °C) to improve its mechanical properties. The temperature of the melt was measured using a Ni−Cr−Ni digital pyrometer.

The casting of the investigated pistons was performed on semi-automatic machines in the PDM-Serbia concern according to a predefined internal procedure by the manufacturer. After being removed from the tool, the piston castings were air-hardened (the air pressure was 4 bar). A "CER Čačak EPC 200/300" furnace with a capacity of 3,000 kg/h and a maximum temperature of 350 °C was used for the stabilization.

An optical microscope (Olympus GX51) with a magnification of up to 1,000x was used to visualize the microstructure. The samples were observed under a scanning electron microscope (SEM) using magnifications between 200x and 5,000x. Qualitative and quantitative assessments of the chemical compositions of the phases were done using an energy dispersive spectrometer (EDS).

3. RESULTS AND DISCUSSION

Figure 1 showsthemicrostructure ofthe piston cross-section, where the successfull intermetallic bond between the ring carrierand the pistonalloy is shown. The microstructure of the ring carrier is shown in the following figures: Figure 1b with a magnification of 200x; Figure 1e with a magnification of 500x; and Figure 2h shows a SEM analysis with a magnification of 2,000x. In this case, the microstructure of the ring carrier consists of lamellar graphite distribution in austenite: ASTM type A or B, size 4−6.

The thickness of the diffusion layer was measured (Figure1f). The results show that the thickness of the diffusion layer formed in the piston alloy is within the range 14.60 to 45.17 μm (the average is 31.19 μm). According to international pistons manufacturer, the thickness of the diffusion layer should be in the range between 10–70 μm [5].

In addition to characterization by optical and SEM microscopy, a qualitative analysis of the phases in the intermetallic bonding layer was conducted by EDX scanning electron microscopy.In the first step, an EDS mapping of the intermetallic bonding layer was made. In addition to the conventional SEM image, the EDX mapping provides a meaningful picture of the element distribution of a surface.

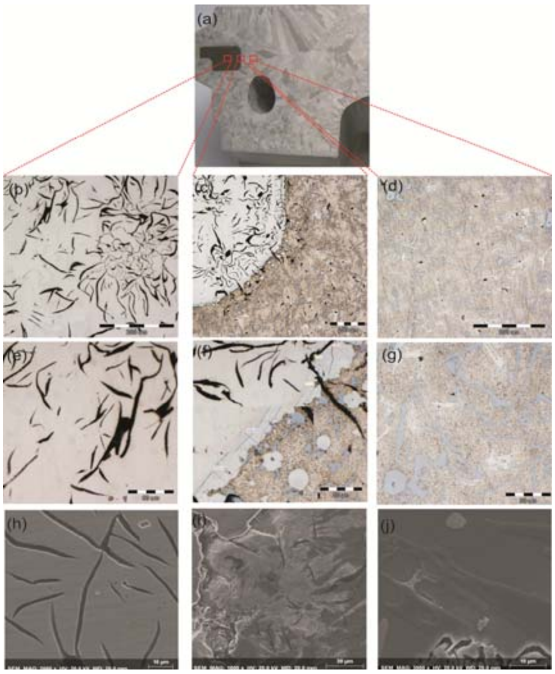


Figure1. Microstructure of the ring carrier-alfin bond-piston

The EDS mapping was done to better identify the precipitated phases. Additionally, the EDS mapping also provides useful information to predict the possible phases where the key elements show higher contrast. Figure 2a shows a SEM analysis while Figure 2b shows an EDS mapping of all the elements in the intermetallic bonding layer. Figures 2c to 2h show the EDS mapping of other important elements (Fe, C, Ni, Cu, Si and Al).

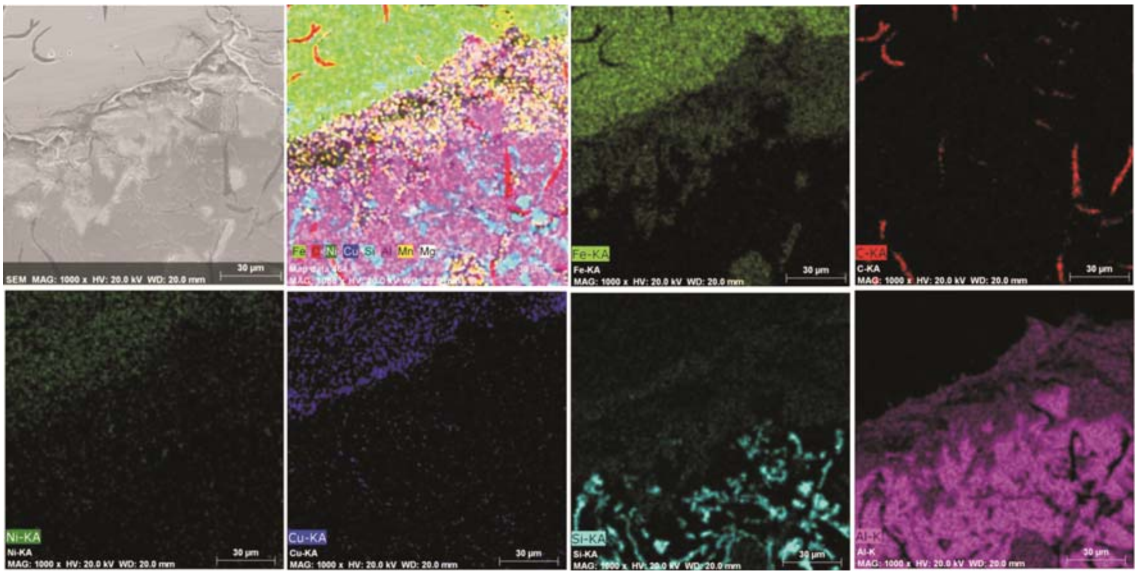


Figure2. The intermetallic bonding layer:a: SEM, 1000x; b: EDS mapping of all elements and EDS mapping; c: Fe; d: C; e: Ni; f: Cu; g: Si; and h: Al [15]

In the second step, a line EDS analysis of element distribution in the intermetallic bonding layer was made. The results of this analysis are shown in Figure 3. The point of line analysis is indicated in Figure 3a while in Figure 3b only for Al and Fe. Based on the obtained results, it can be seen that the Fe concentration decreases and that the Al concentration increases uniformly along the analyzed ring carrier-alfin bond-piston line, depending on the presence of other alloying elements (i.e., there is no discontinuity). Figure 3b shows the corresponding EDS spectra for the phase identified in the intermetallic bonding layer. The EDX results were used to identify the stoichiometry for the particular phases based on the data reported in the literature. The alfin bond is a real bond, which has a chemical composition close to Fe_xAl_y and is formed by the Fe and Al alloy (Fig. 3d).

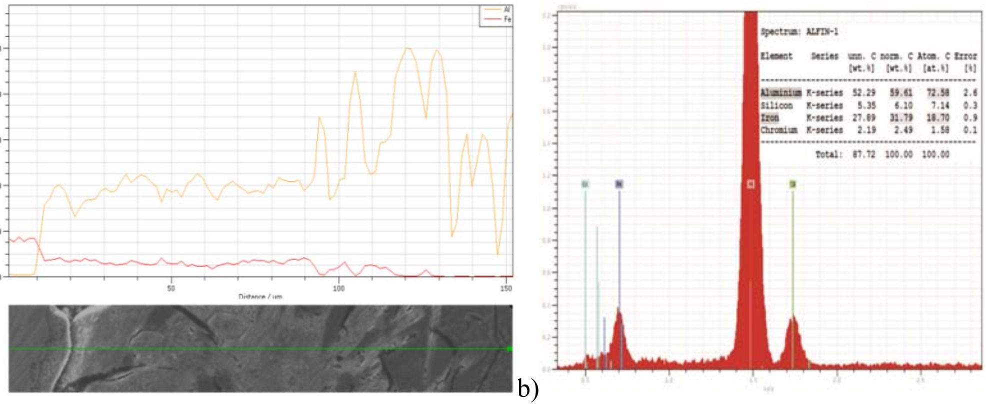
a)  b)

Figure3. Analysis of the intermetallic bonding layer: a: SEM, 1000x; b: EDS analysis changes in all elements; c: EDS analysis, changes in Al and Fe; and d: EDS identification of Fe_xAl_y[15].

4. CONCLUSION

Based on the analysis of the experimental test results presented in this paper and the available data from the literature, it can be concluded that if the manufacturer's instructions defined for casting pistons with the ring carrier are applied completely, a good metal connection can be formed between the two quality materials.

The results presented in this paper are only an introduction to further, ongoing research.

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