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Ceramic protection plates brazed to aluminum brake discs

L. Gorjan [a,*], M. Boretius [b], G. Blugan [a], F. Gili [c], D. Mangherini [c], X. Lizarralde [d], M. Ferraris [e], T. Graule [a], A. Igartua [f], G. Mendoza [f], J. Kuebler [a]

[a] Empa – Swiss Federal Laboratories for Materials Science and Technology, Laboratory for High Performance Ceramics, Überlandstrasse 129, 8600 Dübendorf, Switzerland
[b] Listemann Technology AG, Wirtschaftspark 34, P.O. Box 247, LI-9492 Eschen, Liechtenstein
[c] CRF – Centro Ricerche Fiat, Strada Torino 50, Orbassano, Italy
[d] Fagor Ederlan – Edertek, Garaia Berrikuntza Gunea, Isasi Kalea, 6 – Posta K. 19, 20500 Arrasate-Mondragón, Gipuzkoa, Spain
[e] POLITO – Politecnico di Torino, DISAT – Department of Applied Science and Technology, Corso Duca degli Abruzzi 24, I-10129 Torino, Italy
[f] IK4 TEKNIKER, Parke Teknologikoa, Calle Iñaki Goenaga 5, 20600 Eibar, Gipuzkoa, Spain

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ABSTRACT

Aluminum alloys are light-weight and one of the most interesting material solutions to optimize the strength/weight ratio to reduce car weight; however they are also relatively soft and therefore cannot be used for intensive wear applications. We developed an aluminum alloy part combined with hard and wear-resistant Al_2O_3-based ceramic plates on the surface for demanding mechanical parts for automotive industry such as disc brakes.

Tribological tests of various engineering ceramic materials were performed in order to find a ceramic material with a combination of coefficient, wear resistance and thermal energy dissipation for the car brakes. Al_2O_3-based ceramic showed promising properties, as well as being cost effective.

Two different approaches to braze ceramic on aluminum were investigated. A two-step brazing process using Cu-Sn-Ti-Zr filler alloy and a single step ultrasonic active soldering with Sn-Ag-Ti filler alloy. Larger areas of aluminum could be covered with a segmented brake design in which many ceramic plates were joined surface. Comparable tribological properties to those of the bulk ceramic material were achieved.

1. Introduction

There is a strong interest in the automotive industry to obtain lighter components in order to improve energy efficiency and emission output. The amount of aluminum, used in passenger cars has risen significantly in the past decades, which resulted in improved energy efficiency. It is used in many different components like wheels, engines, heat exchangers, transmission and others. This is possible, because aluminum alloys have several good properties like high strength to weight ratio, excellent thermal conductivity, corrosion resistance and they are easy to machine and recycle. However, they are relatively soft and offer insufficient wear resistance for applications where intensive friction is present. In this paper, an idea to combine a tough and light-weight aluminum body with a hard and wear-resistant ceramic, layer joined at the surface, is explored and evaluated for applicability to automotive disc brakes.

Brazing and soldering are preferred joining techniques when a strong, thermal conductive, temperature and solvent resistant joint is required. This approach has an additional advantage regarding the surface protection of soft aluminum, because it enables to attach a material which was made in a separate process to have well-defined and optimized properties for the desired application.

In the past other ways to improve the aluminum surface have been explored. Typically the surface is improved by applying hard and wear resistant coating on the surface. For example ferrous thermal spray coating [1]. Especially with micro-arc oxidation a very hard and strong layer of Al_2O_3 coating can be prepared [2–5]. Although very good properties were achieved, these promising technologies are not the focus of this paper.

Brazing and soldering of ceramic to aluminum alloys is not a well-established and proven technology. There are two major reasons for that. First, brazing ceramic to aluminum is difficult because molten filler metal does not spontaneously form a strong bonding to the surfaces, especially at the relatively low temperatures which are required to join aluminum alloys. Filler alloys with

* Corresponding author.
E-mail addresses: lovro.gorjan@empa.ch, lovro.gorjan@gmail.com (L. Gorjan).

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a so called active element (most commonly Ti or Zr) are used to braze ceramics. Only moderate bonding strengths (15 – 30 MPa) were reported by using hot pressing of Al_2O_3 to aluminum at 600 °C in vacuum using alloys without an active element such as Al-Si and Al-Cu [6]. When filler alloy contains an active element it can react with the ceramic surface and forms strong chemical bonding [7–17]. The modified surface then enables the wetting of the molten filler. The addition of rare earth elements, such as Ce and Ga also improves wettability, while it also improves strength [18] and the oxidation resistance of the metal in molten state [19,20]. Relatively high temperature is typically needed for the activation of the active element. For example a temperature in excess of 700 °C is needed to achieve good wetting of the Sn-Ag-Ti alloys on Al_2O_3 ceramic [13,14,20,21]. However, high temperature presents a problem for joining aluminum alloys since cast aluminum alloys have relatively low melting points (< 600 °C) and their properties can be compromised at higher temperatures.

The second major challenge in brazing or soldering ceramic to aluminum originates from the different shrinkages of both materials after the cooling to ambient temperature. Large thermal stresses are generated which can compromise the mechanical properties of the composite product. In order to avoid this inherent problem a sophisticated graded material structure or special design in size and shape could potentially avoid the critical issues.

For applications like brake discs, a high precision surface flatness and parallelism is required, which can most likely be only achieved by final grinding, after the ceramic parts have already been soldered on the aluminum frame. During such a mechanical operation possible defects are introduced on the surface of stressed ceramic. An additional important aspect of the research was also the price of the final composite. Only cost effective products would be acceptable for automotive mass application.

In this work the development of composite materials for disc brakes and possibly other friction intensive applications are presented. First a material with the desired friction characteristics was selected for the outer layer of the composite. Then different joining techniques were considered to prepare aluminum/ceramic composite.

2. Experimental

2.1. Concept design

The idea behind the project was to use an aluminum alloy to make a lightweight brake disc body and cover the wear area with a hard and wear-resistant material. The concept is schematically shown in Fig. 1. Cast aluminum alloy is used for a body onto which harder and wear resistant ceramic material is brazed.

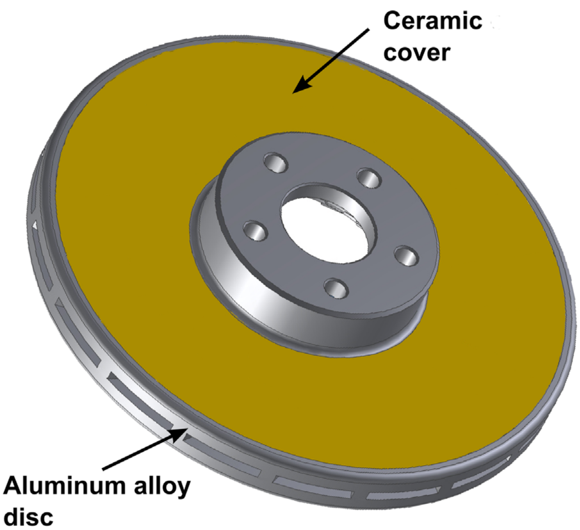

Fig. 1. Sketch of an aluminum braze disc protected by wear-resistant hard material.

2.2. Materials

Materials used in our research are listed in Table 1 together with their basic properties. Two different aluminum alloys were used - A380 and A356, which are widely used in automotive and other industries. Solid sample parts were cast at Fagor Ederlan, Spain, using a low-pressure aluminum casting process.

Several technical ceramic materials were considered for the top layer. After the tribological tests of different bulk ceramic samples we focused on Al_2O_3 ceramic. Material marked as Al_2O_3 was prepared from commercial 99.7% alumina powder (Granalox NM9922, Nabaltec, Germany), pressed and sintered at 1620 °C for 2 h in air.

Materials used for joining wear resistant layers to aluminum alloy substrates are listed in Table 2.

Table 1
List of selected materials used in the research.

Material	Composition	Density [g/cm^3]	CTE [10^{-6}/K]	Thermal conductivity [W/mK]
A380	Al 8.5Si 3.5Cu	2.71	22	96
A356	Al 8.5Si 0.3Mg	2.69	22	160
Al_2O_3	99.7% Al_2O_3	3.93	7.0	27
Al_2O_3-SiC	99.99% pure Al_2O_3 + 5 vol% SiC	3.84	6.8	24
TZ3Y	ZrO_2 + 5% Y_2O_3	6.1	10	2
Mullite	$3Al_2O_3$ $2SiO_2$	3.1	5	6
SiC	SiC	3.2	4	120
ZTA	Al_2O_3 + 8 vol% TZ3Y	4.2	8	20

Table 2
List of materials used for joining.

Material	Type	Composition [wt%]	Melting temperature [°C]
GS220	Solder alloy	92Sn 3Ag 3Ti (Ce, Ga)	220 – 230
Diabraze	Braze alloy	74Cu 14.5Sn 10Ti 1.5Zr	868 – 925

GS220 (MBR Electronics, Switzerland) is an active soldering alloy with the composition of 92Sn3Ag3Ti (+Ce, Ga). It has a melting range of 220–230 °C and it contains titanium as an active element.

Diabraze is Cu-Sn-based active filler metal and was chosen because of its high strength and ability to wet and react with materials which are typically difficult to bond by brazing [22–24]. The good bonding is due to the large amount of the active elements Ti and Zr. Diabraze has been already successfully used to join diamond and boron nitride ceramics with steel substrate [22,24].

2.3. Joining and machining the samples

Two different approaches to bond wear resistant material on top of aluminum part were considered and are sketched in Fig. 2.

a) Two-step vacuum brazing was made using the Diabraze CuSnTiZr braze metal (Fig. 2a). First, the alloy slurry was applied to the ceramic surface and processed at 900 °C in vacuum in order to melt the filler metal and make a strong bonding with the ceramic surface. After the end of this metallization step, the samples were put on the top of aluminum alloy substrate so that the metallization layer was in direct contact with the aluminum alloy. The samples were then heated in vacuum to 555 °C for 15 min. This