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CORROSION BEHAVIOUR OF ZAMAK COMPONENTS IN A HEARING AID

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This paper represents a study case of a contact lamella of Zamak alloy. The contact lamella came from a behind hearing aid device, that was in a harsh environment, with high humidity and elevated temperatures, often combined with increased levels of perspiration from the user and earwax that impair his functionality. On contact lamella made from Zamak was defined the corrosion factor, represented very well in the figures of this paper. By stereomacroscopic analysis and scanning electron microscope analysis there are put in evidence main structural characteristic of the surface after using about 6 years, respectively both corrosion products and corrosion surface.

Keywords: Zamak alloy, corrosion of contact lamella, macroscopy, SEM.

1. Introduction

A hearing aid it's a small electronical device that makes some sounds louder so that a person with hearing loss can listen, communicate, and participate more fully in daily activities.[1]

Early devices were passive amplification cones designed to gather sound energy and direct it into the ear canal. Now, hearing aids are digital electroacoustic systems that transform environmental sound to make it audible, according to cognitive rules. They also utilize sophisticated digital signal processing to try and improve speech intelligibility and comfort for the user. Such signal processing includes feedback management, wide dynamic range compression, directionality, frequency lowering, and noise reduction.[2]

Hearing aids are used for a variety of pathologies including sensorineural hearing loss, conductive hearing loss, and single-sided deafness. Hearing aid candidacy is typically determined by a Doctor of Audiology, who will also fit the device based on the nature and degree of the hearing loss being treated. The

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amount of benefit experienced by the user of the hearing aid is multi-factorial, depending on the type, severity, and etiology of the hearing loss, the technology and fitting of the device, and on the motivation, personality, lifestyle, and overall health of the user.[3]

Hearing aids vary a great deal in, size, special features and the way they're placed in your ear. The following are common hearing aid styles, beginning with the smallest, least visible in the ear. Hearing aid designers keep making smaller hearing aids to meet the demand for a hearing aid that is not very noticeable. But the smaller aids may not have the power to give you the improved hearing you may expect.[4]

Completely in the canal (CIC) or mini CIC

A completely-in-the-canal hearing aid is molded to fit inside your ear canal. It improves mild to moderate hearing loss in adults.

A completely-in-the-canal hearing aid:

- Is the smallest and least visible type
- Is less likely to pick up wind noise
- Uses very small batteries, which have shorter life and can be difficult to handle
- Often doesn't include extra features, such as volume control or a directional microphone
- Is susceptible to earwax clogging the speaker

In the canal

An in-the-canal (ITC) hearing aid is custom molded and fits partly in the ear canal. This style can improve mild to moderate hearing loss in adults.[4]

An in-the-canal hearing aid:

- Is less visible in the ear than larger styles
- Includes features that won't fit on completely-in-the-canal aids, but may be difficult to adjust due to its small size
- Is susceptible to earwax clogging the speaker

In the ear

An in-the-ear (ITE) hearing aid is custom made in two styles — one that fills most of the bowl-shaped area of your outer ear (full shell) and one that fills only the lower part (half shell). Both are helpful for people with mild to severe hearing loss and are available with directional microphones (two microphones for better hearing in noise).[4]

An in-the-ear hearing aid:

- Includes features that don't fit on smaller style hearing aids, such as a volume control
- May be easier to handle
- Uses a larger battery for longer battery life, with several options for rechargeable batteries

- Is susceptible to earwax clogging the speaker
- May pick up more wind noise than do smaller devices
- Is more visible in the ear than smaller devices

Behind the ear

A behind-the-ear (BTE) hearing aid hooks over the top of your ear and rests behind the ear. A tube connects the hearing aid to a custom earpiece called an ear mold that fits in your ear canal. This type is appropriate for people of all ages and those with almost any type of hearing loss.[4]

A behind-the-ear hearing aid:

- Traditionally has been the largest type of hearing aid, though some newer mini designs are streamlined and barely visible
- Has directional microphones
- Is capable of more amplification than are other styles
- May pick up more wind noise than do other styles
- May be available with a rechargeable battery

Receiver in canal or receiver in the ear

The receiver-in-canal (RIC) and receiver-in-the-ear (RITE) styles are similar to a behind-the-ear hearing aid with the speaker or receiver that sits in the ear canal. A tiny wire, rather than tubing, connects the piece behind the ear to the speaker or receiver.[4]

A receiver-in-canal hearing aid:

- Typically has a less visible behind-the-ear portion
- Has directional microphones
- Has manual control options
- May be available with rechargeable battery
- Is susceptible to earwax clogging the speaker

Open fit

An open-fit hearing aid is a variation of the behind-the-ear hearing aid with a thin tube or the receiver-in-the-canal or receiver-in-the-ear hearing aid with an open dome in the ear. This style keeps the ear canal very open, allowing for low-frequency sounds to enter the ear naturally and for high-frequency sounds to be amplified through the hearing aid. This makes the style a good choice for people with better low-frequency hearing and mild to moderate high-frequency hearing loss.

An open-fit hearing aid:

- Is often visible
- Doesn't plug the ear like the in-the-ear hearing aid styles, often making your own voice sound better to you
- May be more difficult to insert into the ear due to the noncustom dome

Zamak is a family of alloys with a base metal of zinc and alloying elements of aluminum, magnesium, and copper.[5] Zamak alloys are part of the zinc aluminum alloy family; they are distinguished from the other ZA alloys because of their constant 4% aluminum composition.[6] The most common zamak alloy is zamak 3. Zamak 3 is the de facto standard for the Zamak series of zinc alloys; all other zinc alloys are compared to this. Zamak 3 has the base composition for the zamak alloys (96% zinc, 4% aluminum). It has excellent castability and long-term dimensional stability.[6]

Some component inside of the hearing aids are formed by metal alloy. Contact lamella with battery were many years made by ZAMAK alloy. Certain harsh environments, such as places with high humidity and elevated temperatures, often combined with increased levels of perspiration from the user and earwax can impair the functionality of the devices. Electrical contacts (low power) in these devices are critical components, which limit the hearing aid performance in such situations, leading to reduced battery life, power dropouts and increased acoustic feedback (whistling) in the device output.

Zamak is a non-ferrous metal alloy basically formed by zinc, aluminum, magnesiumand copper which together give rise to its name [7]. The combination of these elements confers the Zamak alloys a low melting point, which allows the largescale production of squeeze casting pieces due to good fluidity. This characteristic facilitates the obtaining of pieces with complex geometries and thin walls besides a good mechanical resistance, which are characteristics that promotes a widespread application of these parts [8]. As a result, Zamak has been widely used in the metallurgical, automotive, electrical and electronic industries [7,9,10]. However, a fast solidification of the Zamak during squeeze casting causes porosity defects due to the trapping of gases and steams in mold cavities [11], but formation of these microporosities also depends on pressure, although this is not the only characteristic influencing its presence [12,13]. As well it is noteworthy that the presence of these porosity defects has shown a negative influence on the corrosion resistance of the alloy [11,14]. To minimize these defects, increase corrosion resistance and provide a more visually attractive appearance, industry make use of finishing processes to cover these pores. Usually these finishing processes correspond to a mechanical polishing, a copper electrodeposition process [15] or a combination of these, including chrome sputtering coating [16].

On the other hand, the anodizing process has been widely used in valve metals, which undergo oxidation in contact with air. Valve metals are aluminum [17], titanium [18,19], niobium [20,21], tantalum [22] and tungsten [23], with aluminum (alloying element of Zamak) being the most anodized metal.

Gravity cast zinc-aluminum alloys containing 60-85% by weight of zinc can be anodically oxidized in aqueous solutions of sulfuric acid to produce films that are basically aluminum oxide with only small zinc content, probably as oxide, of about 5-10% by weight of the anodized film [24].

Zamak 3 (ASTM AG40A), or Zinc Alloy 3 is usually the first choice when considering zinc for die casting for a number of reasons:

-Excellent balance of desirable physical and mechanical properties

-Superb castability and long-term dimensional stability

-Excellent finishing characteristics for plating, painting, and chromate treatments

-Excellent damping capacity and vibration attenuation in comparison to aluminum die cast alloys

Zamak 3 also offers excellent finishing characteristics for plating, painting and chromate treatments. It is the "Standard" by which other zinc alloys are rated in terms of die casting. As a family of Zn alloys, Zamak alloys, with a eutectic composition range of Zn–Al binary alloys, have good fluidity and formability in casting process.[25] Therefore, Zamak alloys have been widely used in engineering applications, such as in the small components and plane bearings of automotive vehicles.[26] Among Zamak alloys, the Zamak 3 alloy is considered a reference standard and has been widely used. However, the low strength of the Zamak 3 alloy leads to a high poor wear resistance, which restricts it is application in many fields. As such, it is of importance to enhance its strength. Because of the well-known tradeoff between strength and ductility, severe plastic deformation (SPD), such asequal-channel angular pressing, high-pressure torsion, and accumulative roll bonding, can significantly improve metal strength but remarkably deteriorate their ductility [27-31].

When considering zinc alloys for die casting, Zamak 3 is typically the first choice due to its excellent cast-ability—an elusive property which combines flowability which in turn depends on melt viscosity and freezing range. It has also been found to have good finishing characteristics for both plating and painting/lacquering. This latter point is especially important in the toy sector where decorative presentation has to provide not only good aesthetics but needs to be robust too.[31]

Galvanic corrosion is a phenomenon that occurs when two different metals are in contact with each other in the presence of an electrolyte such as salt water. A current will be generated flowing from the anodic or baser metal to the cathodic or nobler metals. In essence the anodic material will actually plate itself on the cathode. Galvanic corrosion can occur in some cases, even when dissimilar metals, which are not in direct contact, are connected by a common electrolyte. The severity of the galvanic corrosion is proportional to the conductivity of the electrolyte. Exposure trials showed no significant galvanic corrosion attack after five years of atmospheric exposure on ZA alloys coupled to engineering metals such as copper, lead and mild steel. Zamak alloys would be expected to behave similarly.[32]

Another factor, which affects the rate of galvanic corrosion, is the proportional size of the anodic and cathodic materials. The worst conditions usually occur when a small anode is connected (physically or electrolytically) to a large cathode. For example, zinc bolts on a submerged, steel oil drilling platform will quickly corrode, as the zinc will attempt to galvanize the steel structure.[32]

Although not feasible for other reasons, steel bolts on a zinc oil-drilling platform would present a problem, as a sufficient quantity of zinc is present to plate the steel bolts without affecting the integrity of the structure.

Galvanic corrosion can be prevented by:

1. Insulating the dissimilar metals from contacting each other, by use of a non-conductive gasket material.

2. Breaking the electrolytic path between the two metals if they are not connected physically, by coating the components with a non-conductive finish.[32]

The introduction of 99.99% pure zinc (SHG – Special High Grade) as the base for zinc aluminum casting alloys, effectively and completely eliminated intergranular corrosion under normal service conditions. However, intergranular corrosion can still occur under wet or damp conditions if zinc-aluminum alloys are exposed to temperatures above about 700C (1580F). When present above normal specification levels, Sn, Pb, In, Cd, Bi, Hg, and Th can promote intergranular corrosion, so every effort must be made to ensure that all zinc castings meet the appropriate ASTM standard. Copper and Magnesium are present in the alloys to help prevent intergranular corrosion. Zamak 7 is not recommended in hot and humid environments due to low quantities of CU and mg present in this alloy.[32]

Present paper considers a case study concerning the corrosion behavior of a contact lamella made of ZAMAK 3 alloy, at a Behind the Ear hearing aid. Finaly a recomandation was made for improving the corrosion resistance of the hearing aid pieces.

2. Materials and Experimental Procedure

Structural analyses were made on a contact lamella from a male patient that lived in a region with high content of NaCl in atmosphere. Contact lamella from a behind the ear hearing aid, that worked 3 years. The chemical composition of the experimental Zamak alloy is illustrated in table 1. In order to highlight the structural aspects of the surface of the contact lamella, the techniques corresponding to the Stereomicroscope and SEM analyzes were used.

The stereomacrostructural analysis was performed on the OYMPUS stereomicroscope type SZX equipped with QuickMicroPhoto 4.4 processing software. SEM analysis was performed on a scanning electron microscope, SEM, PHYLIPPS type.

Table 1-

Chemical composition of the experimental Zamak alloy [11]

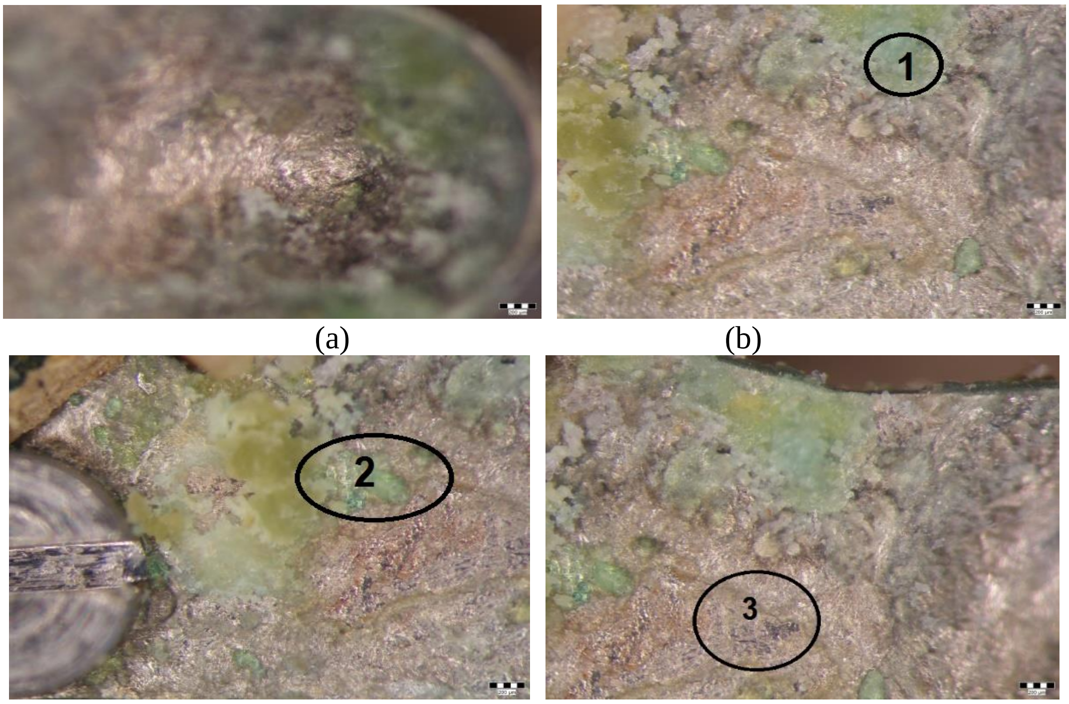
Zamak 3 chemical composition, %wt												
		Alloying elements			**Impurities**							
Alloy	**Limit**	**Al**	**Cu†**	**Mg**	**Pb**	**Cd**	**Sn**	**Fe**	**Ni**	**Si**	**In**	**Ti**
Experimental		4.15	0.09	0.040	0.004	-	-	0.025	-	-	-	-
ASTM B240[21] (Ingot)	Min	3.9	-	0.025	-	-	-	-	-	-	-	-
	Max	4.3	0.1	0.05	0.004	0.003	0.002	0.035	-	-	-	-

3. Results and Discussions

As can be seen from Table 1, the investigated alloy is ZAMAK 3 and has a chemical composition that corresponds to the brand requirements. By stereomicroscopic analysis made on OLYMPUS stereomicroscope there are put in evidence both corrosion products and corrosion surface (cracks and pitting, as is illustrated in Fig. 2). As it can be seen from the analysis of Fig. 1, the lamella is thus positioned inside the device, like in Fig. 1a and 1b. This position led after use for a long time. When corrosion products appear on the surface of the lamella, highlighted in the detail images in fig. 2a and 2b. Corrosion products are white-green in color and have caused both general corrosion phenomena and localized corrosion phenomena, as is illustrated in dots 1, 2 and 3.

(a) (b)

Fig. 1- Stereomicroscopic images of the hearing aids:
a-position of the lamella in the hearing aid; b- macroscopical aspect of hearing aid contact lamella

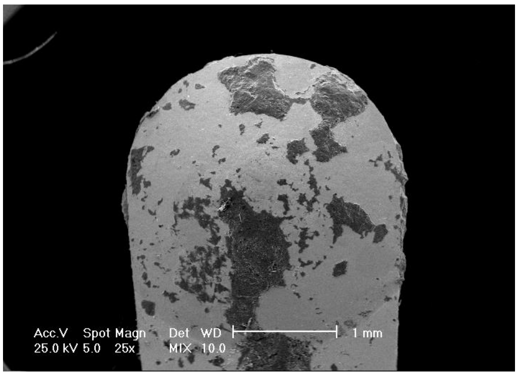


(a) (b)

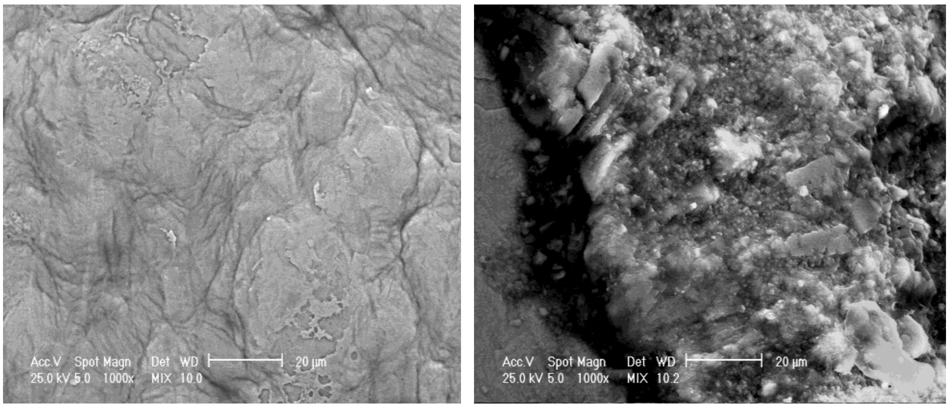
(c) (d)

Fig. 2- Stereomicroscopic images of the hearing aids lamella with corrosion surfaces:
a-front image of the lamella; b- corrosion points of the lamella surface from the right edge of the piece; c- corrosion points of the lamella surface from the left edge of the piece;
d- localized corrosion of the lamella

Scanning electron microscope (SEM) analysis of the ZAMAK contact plate showed corrosion also at the macrostructural aspect and in microstructural aspect, as is given in the Fig. 3. In Fig. 3 (a) the macrostructural aspect of the contact lamella is highlighted, showing dark areas due to the corrosive action of the environment in which the hearing device operated (inside the ear).

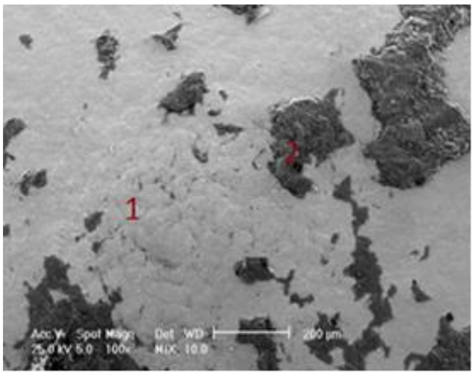


a

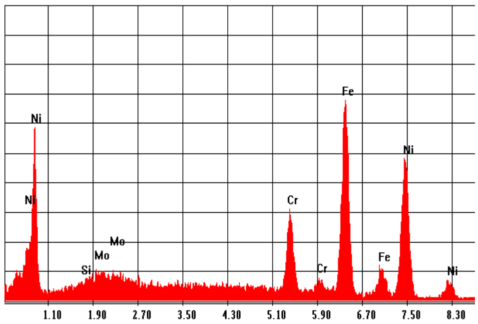


b c

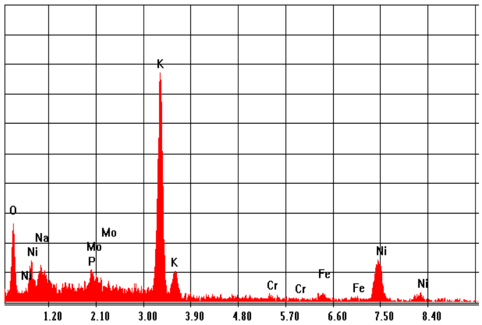
Fig. 3 Macrostructural aspect of the contact lamella:a-corrosion areas;
b-wavy surface due to the erosion;c-corrosion products



a



b



c

Area	Local Microcomposition, wt%							
	Si	Mo	Cr	Fe	Ni	Na	K	O
1	1.41	3.57	10.81	40.26	43.94	-	-	-
2	-	1.48	0.82	2.08	24.59	14.02	39.05	14.78

Fig. 4 - Scanning electron microscope (SEM) and EDS analysis of the ZAMAK contact plate: a- surface aspect of the piece revealing corrosion products; b- EDS analysis of the indicated points in image a; c- local microcomposition of the indicated tones in image a

The microstructural aspect is detailed in Fig. 4 (a), noting the two distinct areas, namely light-colored area 1, free of corrosion products and area 2, dark area, with corrosion products. Area 1, detailed in Fig. 3 (b), has a wavy /chamfered surface, which is due to erosion resulting from the intermittent contact of the Zamak plate to ensure electric flow. Area 2, detailed in Fig. 3(c), shows traces of corrosion products, with friable appearance, less than 10mm thick. These corrosion products are rich in sodium and potassium oxides. The results regarding the local microcomposition of the investigated areas highlight the nature of the material from which the lamella is made, respectively Zamak and on the other hand, the chemical composition of the corrosion products.

4. Conclusions

The paper presents a case study on the corrosion behavior of a contact blade belonging to a hearing aid in a male patient after 3 years of use. Investigations performed on the optical stereomicroscope revealed the position of the lamella both inside the hearing aid and the appearance of the corrosion phenomenon (localized and galvanic) on the surface of the lamella. Corrosion products were deposited in the areas of contact with the inside of the human ear and it was white-green color. The SEM-EDS analysis allowed the identification of the local microcomposition of the corrosion product and on the other hand highlighted their existence. In order to improve the corrosion behavior of the contact lamella used for the hearing aid, we propose either the modification of the chemical composition of the Zamak alloy, or the use of lamella with metal coatings.

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