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Active functionality of piezoceramic modules integrated in aluminum high pressure die castings

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ABSTRACT

Based on high pressure die casting (hpdc) technology, this study deals with the integration of piezoceramic modules into aluminum castings. Despite of the severe thermal and mechanical loads during the casting process, a successful integration of polymer based piezoceramic modules is possible. Measurements show the influence of the distance of the module to the neutral axis on the functionality. In addition wall thickness influences the performance of the module. In order to quantify the efficiency of the actuatoric functionality in the integrated state, a beam bending model is used. A comparison of the theoretical to the experimental behavior shows nearly no loss of module performance in thin-walled parts but a decrease of the performance with increasing wall thickness.

1. Introduction

In automotive industries lightweight construction is an important trend to reduce fuel consumption. The substitution of traditional materials by lighter materials such as aluminum or magnesium is one approach to minimize weight. Unfortunately, the use of light metal parts results in vibration and noise increase [1]. The combination of functional modules, e.g. piezoceramic sensor/actuator-modules, and structural components is one opportunity to create parts with the ability of active vibration control [2]. The combination can be achieved simply by bonding the sensor/actuator-modules onto the components' surface using an adhesive layer. However, this method has several disadvantages. Firstly, the ceramic is not protected against external influences like foreign object damage or humidity as it happens in the environment of structural components, e.g. used in automotive industries. Secondly, the adhesive layer is also subjected to external influences. Thirdly, bonding onto the surface is an additional production step that results in increased costs.

In recent studies two main approaches for integrating piezoelectric elements into aluminum structures can be found: by means of forming and casting. Neugebauer et al. [3] developed production technologies to manufacture sheet sandwich structures with integrated MFCs (macro fiber composites – M 8528-P1, distributor: Smart Materials GmbH, Dresden, Germany). Schubert et al. [4] follows a different approach with aluminum sheets. A direct integration is implemented by micro forming processing. DLC or SiCN:H [5] coatings are applied for isolating purposes in the created micro cavities. Afterwards piezoelectric fibers are placed in the cavities and clamped in the aluminum sheet by plastic deformation of the bridges between the micro cavities.

Staeves [6] postulates the integration of piezoelectric modules by means of casting as a promising approach to detect and even act against damage of lightweight casting components in automotive applications. Studies for the integration of PZT-modules in aluminum castings are published by Busse et al. [7,8]. Piezostacks are integrated into a covering aluminum body for sensory purposes. Contrary to the approach presented in this study, the casting process is not performed to create a structural component but a protective enclosure.

The present work is based on the concept of creating lightweight thin-walled components by aluminum die casting. Production

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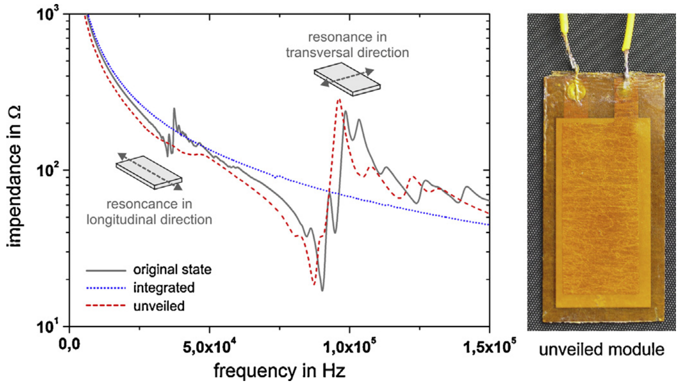

Fig. 1. Impedance measurements of PZT-modules of initial, integrated and unveiled state (left) and unveiled module (right) [10].

technology and basic functionalities of the piezoelectric composite structure are presented by Rübner et al. [9]. Furthermore Klassen et al. [10] shows, that the casting process itself has no negative influence on the performance of the PZT-module, see Fig. 1.

In this study piezoceramic modules are integrated into castings with varying wall thickness. Furthermore the position of the module with respect to the neutral axis of the casting is altered, in order to change the lever arm of the applied module force. The functionality of the modules is determined by quasi-static deflection measurements by laser triangulation. Even though the main aim is to create a damping effect with the piezoelectric modules for high cycle applications, deflection measurements are carried out with very low cycle values in order to understand the basic behavior of the intelligent casting compound. The performance of the modules is evaluated by applying a beam bending model.

2. Methods

2.1. Casting technology

Casting experiments are carried out using a cold chamber high pressure die casting machine DAK 450-54 (Oskar Frech GmbH & Co. KG) with a maximum closing force of 458 tons. The casting plunger reaches max. velocities of 2 m/s and after the complete filling of the mold cavity, a dwell pressure of about 750 bar is applied to reduce shrinkage and porosity. The mold is tempered at 150 °C during the casting experiments. In addition a vacuum system is applied to reduce gas and solidification porosity beneath a value of 1.0% in the casting.

For the experiments the standard die casting alloy 226D – AlSi9Cu3(Fe) is selected. For this alloy the liquidus and solidus temperature are 593 °C and 521 °C, respectively [11].

2.2. Integration of PZT-modules

Commercially available modules (DuraAct, distributor: PI Ceramic GmbH, Lederhose, Germany), which operate in the lateral extension mode (d_{31}-mode) are used. Fig. 2a illustrates the cross section of the module. The piezoceramic foil PIC255 of rectangular dimension (28 mm × 14 mm × 200 μm) is embedded within an epoxy-matrix and covering films of Kapton HN polyimide (DuPont). The ceramic is metallized on the bottom and the upside to form electrodes. Copper meshes provide sufficient electrical contact between the metallized surfaces and the electrical contact points which are soldered to contacting wires [10].

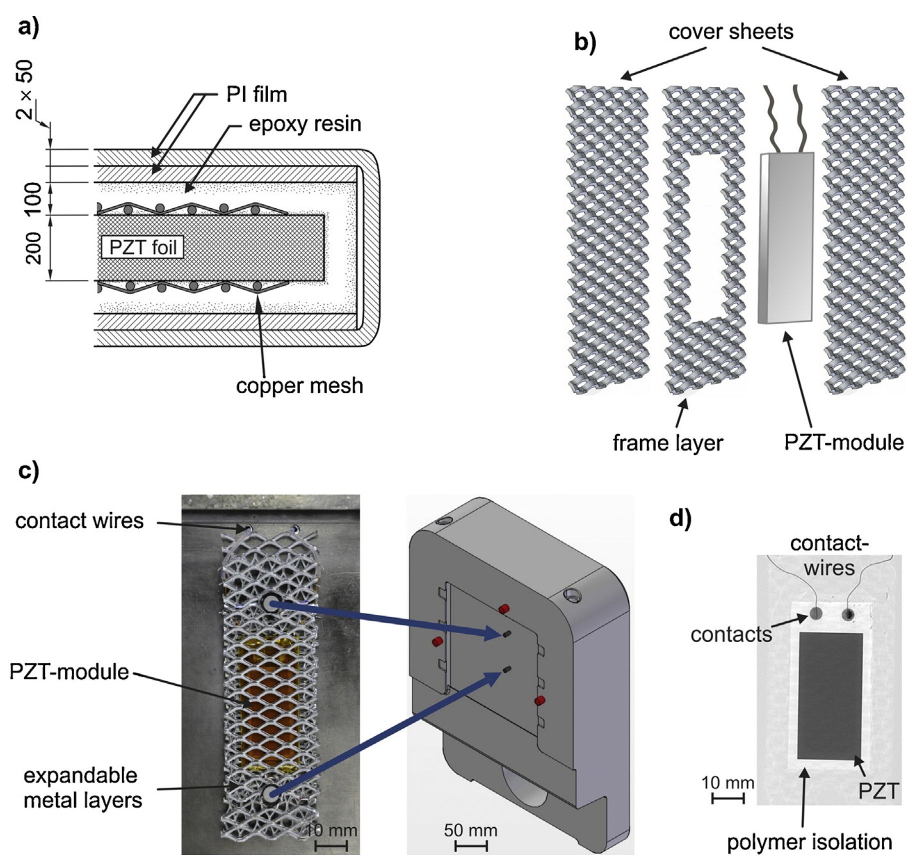

Fig. 2. (a) Schematic illustration of PZT-module [10]. (b) Basic design of insert including the PZT-module. (c) Positioning of insert in casting mold. (d) Radiography of casting with PZT-module.