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Structural integration of piezoceramic fibers in deep drawn sheet metal for material-integrated health monitoring

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ABSTRACT

The integration of active piezoceramic sensors and actuators into passive sheet metal assemblies produces smart structures. Smart structures are capable of sensing the condition of parts and systems as well as interacting with the environment. Today, smart sheet metal parts are manufactured by surface bonding of sensors and actuators on shaped structural parts. This paper presents a technology for the direct structural integration of lead-zirconate-titanate (PZT) fibers. The fibers are integrated in flat sheet metal, which is subsequently shaped by forming. Microcavities are formed into the surface of the flat metal sheet in which the piezoceramic fibers are inserted and joined. After that, the composite is shaped into a complex 3D surface by deep drawing. The production technology is discussed in detail with regard to the limits of each process step.

Functional prototypes with ten interconnected parallel piezoceramic fibers were fabricated. The function as actuator and sensor for ultrasonic elastic waves is demonstrated and the degradation due to the shaping is compared for different parameters of the deep drawing process. The composite shapes are cups with a double curvature radius of 100 mm and 250 mm respectively.

As a result, degradation of the piezoelectric function varies with the process parameters. In the case of a double curvature of 250 mm, a degradation of the transducer function of 20% was shown in the experiments. The cause of the decreased performance after shaping is discussed and explained by debonding mechanisms. Results of numerical simulations show a good agreement with the experimental findings of the optimum process parameters.

Furthermore, a setup of a wing assembly segment is used to demonstrate the potential of integrated PZT fibers in shaped metal structures. The integrated fibers are used for health monitoring of a multiple bolted joint. It is shown that loosening of a single screw can accurately be detected by the directly integrated PZT fibers.

1. Introduction

Today, lightweight components are used in nearly every branch of industry. Especially in the automotive industry [1], in machine tools and aerospace industry structural parts are required to be lightweight and stiff at the same time. By reducing the amount of material and by use of lightweight materials these goals can be reached up to a certain level [2]. In order to achieve further weight reduction, function integration into structural parts, particularly into metal sheets, is a promising technology. Additional active components are replaced by the structurally integrated active sensors and actuators. The integration of active elements can help to reduce weight and to meet the requirements on structural stiffness [3].

Typical fields of applications for smart structures are vibration control [4,5] and active noise reduction [6,7]. Structural vibrations at resonance frequencies often cause noise. Piezoelectric materials allow for a detection and reduction of critical vibrations. Moreover, smart materials can be used in health monitoring of parts and structures. Sensing of the impedance signal was used to detect damages in railroad tracks [8], in a bolted joint, in a gas pipeline and in composite structures [9]. Therefore surface-bonded

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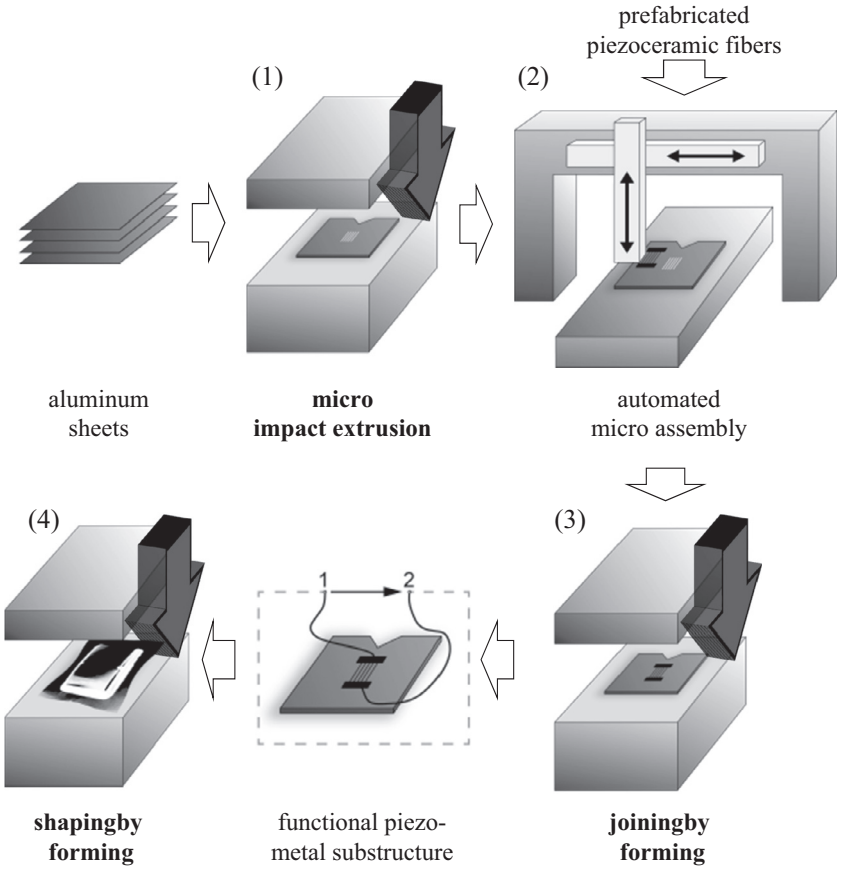

Fig. 1. Process chain for manufacturing shaped structures with integrated interconnected piezoceramic fibers.

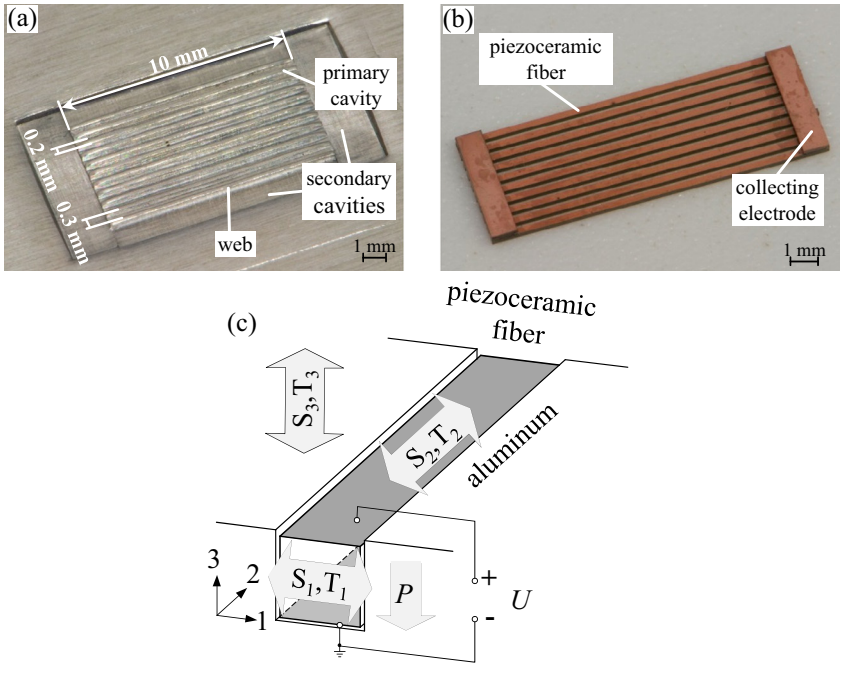

Fig. 2. (a) Dimensions of the microformed microstructure; (b) interconnected piezoceramic fibers; (c) function principle of piezo metal substructure.

piezoelectric transducers (Macro Fiber Composites, MFC) were used. They consist of piezoceramic fibers, layers of adhesive and interdigitated electrodes sandwiched between polyimide cover layers [10]. The detection of damages in pipelines was investigated using a structural health monitoring system based on MFCs and different analysis methods (lamb wave detection, impedance measurement) [11]. Furthermore wing skin-to-spar joints were monitored using guided waves and MFCs [12].