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Condition monitoring of the strength and stability of civil structures using thick film ceramic sensors

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ABSTRACT

Structural Health Monitoring (SHM) is about the mechanical strength and stability of a structure. The methods used to reveal and quantify the structure quality could be different in nature. Strain change is, however, the common structural parameter indicating structure condition in time. Strains can give rise to cracks in civil structures that will grow exponentially in time. The most common way of measuring strain in structures is by using the Metal Foil Strain Gauge (FSG). This paper proposes the use of Thick Film Ceramic Strain Gauge Sensors (TFCSs) as an alternative to measure strain on beams. A 4-point bending test (4PBT) was conducted to show the difference in response of the mentioned two kinds of strain gauges; TFCS and FSG, and then thick film ceramic sensor was applied to observe the stability of sample brick column.

1. Introduction

The common way of measuring strains on structures is by applying Foil Film Strain Gauges [7], widely known as strain gauges. Myriad shapes and configurations of such foil strain sensors, suitable for force and torsion measurements on various structure geometries, are commercially available (Fig. 1a). On the other hand application of Thick Film Sensors (TFSs) is a well-consolidated technology that has been used for many years to build pressure transducers as in Fig. 1b.

Certain thick film pastes placed on ceramic substrate with conventional silkscreen technique has a piezo-resistive effect, i.e. will change in resistor value with strain developed on the ceramic substrate.

Ceramic is a recognised material of high elasticity, corrosion and abrasion resistance, strong shock and vibrant resistance. The thermal stability can make its operating temperature range from −20 °C to +80 °C and withstand high voltages which might exceed 2 kV. It can provide strong output signal and excellent long-term stability.

The Thick-Film materials are known for their survival, longevity and reliability in harsh environments, extreme temperatures and high mechanical stresses, such as those present in automotive applications [8]. This fact makes Thick-Film technology a good candidate for civil engineering applications. The authors showed experimentally the linearity and proportionality of response of Thick-Film Strain Sensors when applied on building materials like bricks and concrete [6].

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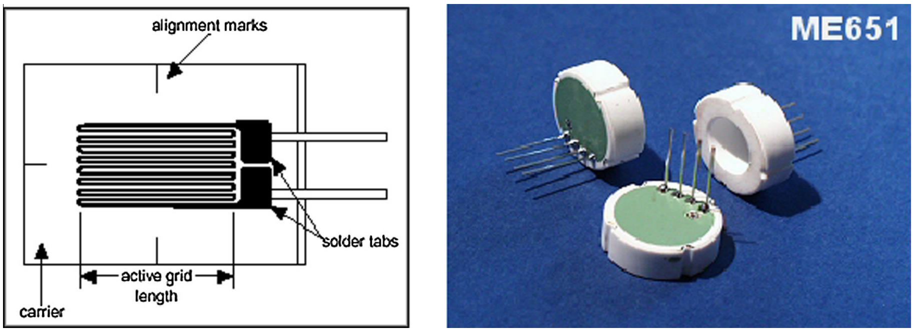

Fig. 1. Examples of (a) metal film strain gauge and (b) ceramic pressure membranes.

Table 1
Characteristics of strain gauges materials [4].

Material	GF	TCR–PPM (°)	TCGF–PPM (°)	Stability
Metal sheets and films	1–2	20	100	Excellent
Silicon single crystals	50–80	1000	−1500	Good
Thick Film resistor	2–35	50–200	−300	Very good

In general, piezo-resistive materials used for strain gauge applications are classified into three groups: thin metal films, thick film resistors and semiconductors. As can be seen from Table 1 [4] below, thick film strain gauges are an excellent compromise between the performance characteristics of the other two types of strain gauges, i.e. thin metal films and semiconductors. Also, in-line print and fire thick film manufacturing is simple, economical and reliable. High Gauge Factor (GF) thick film resistors are used in a wide variety of low cost, high reliability strain gauge and sensor applications. Over the past two decades several applications of thick film strain gauges, including those for commercial purposes, have been studied. Device performance characteristics with advantages and limitations of such applications have been reported by Stecher et al. [5], Dell'Acqua [3], and [4]. These applications include acceleration, force, pressure, weight, computer joy stick or pointing stick. Some high gauge factor thick film pastes exhibit gauge factors in 14–20 range for sheet resistance in the range of 1 kΩ/sq to 10 kΩ/sq, and low temperature dependence [2].

Table 1 shows the main characteristics of TF strain sensors with respect to metal foil and silicon strain gauges. The combination of relatively high gauge factor and temperature stability in addition to mass production capability and low cost are the major factors justifying implementing this technology to build reliable force and pressure sensors in general.

2. Thick Film sample preparation

For the purpose of the investigation for the deployment of Thick-Film sensors on beams used in civil structures, a single Thick Film (TF) resistor was developed on 0.3 mm thick, 96% alumina substrate (Al_2O_3) as shown in Fig. 2.

The piezo-resistor aspect ratio (W:L) was 1.3. The paste used was the DP2041 with a gauge factor of 10. This paste is widely used for TF sensors. Sheet resistance was 10 kΩ/sq. The resistance value obtained was in the range of 7.2–8 kΩ. The medium value of the samples was of 7.5 kΩ. Sensor dimensions are 4.9 × 4.9 × 0.275 mm.

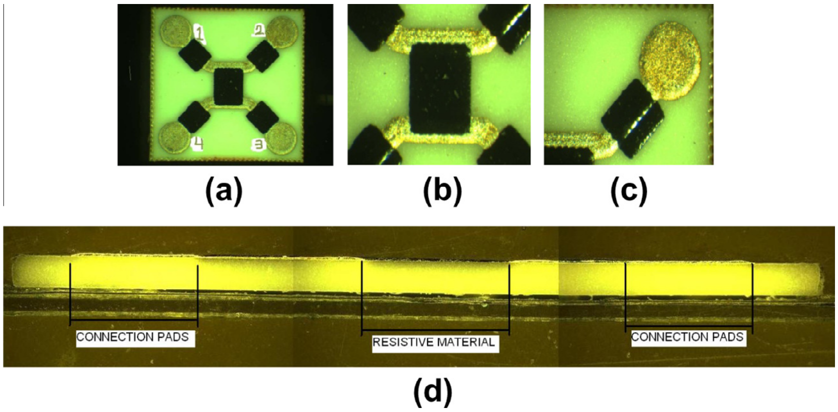

Fig. 2. (a) Thick film piezoresistor on ceramic, (b) only the resistive part without terminals, (c) one connection terminal, and (d) magnified side view.