Inner Car Smart Flooring for Monitoring Chassis Deformation

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Abstract - **This paper presents a novel inner car smart flooring concept able to monitor chassis deformation during the car lifecycle or when a car accident occurs. The proposed smart structure uses Fiber Bragg Gratings (FBG) sensors embedded into standard laminated polymeric sheets used in the automobile. The fabrication was made using an industrial process and the characterization of the resulting polymeric foil able to sense and gather sensitive data was performed. It was verified that the fabricated foil is capable of transferring the full deformation to the optical sensor. The FBG sensor, after incorporation in the polymeric foil, is fully functional with a behavior of 0.6 pm/με (picometer per microstrain), and measuring displacements up to 1.2 mm. The integration process of FBG based-sensors in Polyvinyl Chloride (PVC) foils is described in detail, enabling the industrial mass production of large sensing foils fully customizable for automotive applications.**

I. INTRODUCTION

With the growing concerns about fuel rising prices and greenhouse gas emissions, the automotive industry is facing a demand to develop more fuel-efficient vehicles. Besides the vehicle's powertrain performance and exterior design, its mass is one of several major issues that influence the vehicle's fuel economy. Because an automobile is an engineering system, a change in the structural mass may have an adverse effect on the vehicle crashworthiness. Consequently, the challenge is to design lightweight structures that meet the performance and safety requirements and are still economical competitive [1]. Manufacturers are developing efforts to provide safer vehicles or to reduce vehicle weight by using composites materials or new frame designs, among other developments. The inherent advantages of composites for reducing weight and improving stiffness is clear, however the internal behavior under impact may present some concerns. Also, the automotive industry, among many others, is already benefiting from the potential sensing technologies [2-3]. Consequently, a sensing network can be incorporated in the car chassis for monitoring its structural integrity. However, the direct incorporation of sensors creates some difficulties in eventual sensor maintenance or replacement. Alternatively, it is proposed the integration of sensing instrumentation in usual car coverings as the floor and roof, taking advantage of the fact that these items are typically interconnected with the car structure, and can easily be replaced or applied to different automobile models.

Linking textiles-polymer-laminates (artificial leather) with sensors is more realistic than ever. Therefore, for automotive makers and insurance companies a powerful diagnostic tool as the proposed inner smart flooring for monitoring the chassis deformation in case of collision, car accident or in crash tests will be a breakthrough.

II. MONITORING SYSTEM DESIGN

The integration of a sensor network in the automobile cockpit coverings allows the retrieve of the integrity frame status. The monitoring system can be designed as presented in Figure 1. A study about the chassis structural dynamics is first conducted. This analysis provides the crucial spots of the structure. The pillars, floor and roof are usually considered critical sections, since they undergo higher bending and torsion stress. Thus, it is advisable to place the sensors around these sections. So, it is important to foreknow where the sensor should be place inside the covering foil during the covering fabrication. The covering layer, in the automotive manufacturer, is usually attached to the frame structure by vacuum thermoforming or in some simple structures, as the floor, by glue. By both manners, the foil is well connected to the frame structure, following all the frame behavior.

An on-line system can be then incorporated in the car for processing all the sensors data. If the sensors detect a change that goes above a predefined threshold of strain, a light sign appears in the dashboard, warning the driver. The automotive maker will, then, have the opportunity to connect a more complex processing unit to the car and make an overall check-up of the structure. The result of such analysis will be the strain map of the car chassis frame. With such graphic information, the manufacturer employee will be able to detect the spot that is triggering the alarm and, consequently, fix the defect.

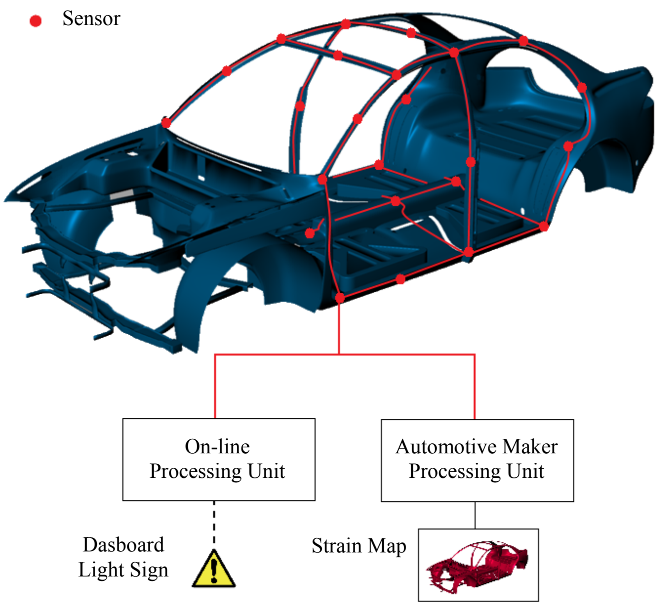

Figure 1 – Illustration of the monitoring system approach.

The sensing network that is to be integrated in the car coverings is not yet accessible for the automotive manufacturers. Some flexible sensing structures can be found but, its fabrication cannot compete with the volume of orders of covering materials by the automotive manufactures. A sensing solution needs especially made at an industrial environment needs to be first developed. The best approach for achieving the sensing structure is to use a technique that allows the manufacturing of trims that can be already found in the majority of the automotive interior [4].

A. Fabrication Process

The spread-coating process (Figure 2) is a very flexible technique, used for many different products, including the automobile trims. It consists on the spreading of polymer pastes over a moving substrate or carrier (e.g. release paper). The running substrate drives the polymer through a gap between the knife and the substrate, defining the layer thickness and scrapping off the polymer excess.

After the coating application as uniform plastisol layer over the substrate, the whole metal frame is inserted in the oven to cure. After heated above the curing-temperature (130 to 400 ºC), the polymer becomes homogenized and a solid phase results. The above described equipment sequence composed of an application unit followed by an oven, is repeated several times to form an industrial production unit that enables the manufacturing of complex laminates for automotive applications. Such complex laminates can be composed of several polymeric layers bonded to flexible substrates like foams, webs and other textile materials.

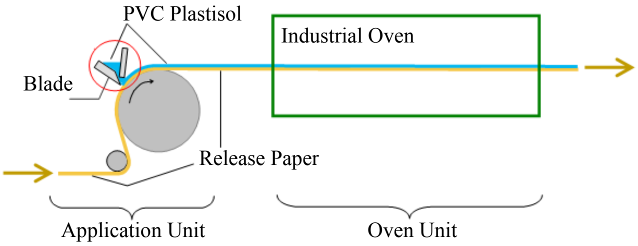

Figure 2 – Spread-coating process schematic.

B. Material Selection

In automotive applications, the need for discrete and integrated sensing solutions is much more relevant for areas where free space cannot be misused. This is particularly the case in interior areas, where safety concerns and comfort may generate strong needs for sensing devices. In automotive interiors, any kind of functional device should be integrated in the most discrete and elegant manner, in harmony with what the eyes of occupants can see. The car interior is mostly made of soft-touch surfaces, like leather or leather like materials, textiles, carpets, mats, etc. In the context of a flexible integrating approach for sensor systems, a flexible skin-like foil for automotive interiors is therefore the base material for the scope of this work.

As the research is focused on the development of a generic manufacturing technology for a flexible optical sensing foil, it was decided to choose a polymer matrix that can be applied for the most interior trimmings, with an acceptable average quality and price. The choice was set on plasticized Polyvinyl Chloride (PVC), for its general good cost/performance ratio and ease of use during manufacturing processes. PVC is one of the most versatile plastics, still playing a major role in the automotive market. Furthermore, PVC exhibits many advantages like highly competitive production cost, high versatility in interior trim applications, high resistance to ageing and ease of maintenance, among others [4-6].

C. Strain Sensor Selection

In common with other aspects of everyday life, the use of optics is becoming increasingly important for automotive applications. Its principal benefit is the potential for highly accurate measurement and position sensing without any mechanical contact, hence greater reliability [7]. Presently, electronics and photonics account for nearly 25 percent of total vehicle manufacturing costs for luxury models [8]. In this context, the development of advanced optoelectronic systems with integrated sensing and data transport capabilities is a key step for the implementation of a new generation of intelligent vehicles. Currently, more than 40 vehicle models are equipped with a fiber optic communication network [9]. These optical links typically use plastic optical fibers and provide, at a low cost, the necessary bandwidth for an increasing amount of data arising from a diversity of sensors and actuators, and multimedia data streams. Optical fiber sensors offer competitive and sometimes unique solutions to many different problems [9-10]. Among the optical fiber sensors, the Fiber Bragg Gratings technology is becoming more and more requested for structural monitoring applications [11]. Fiber Bragg Gratings (FBG) consists in a periodic modulation of the refraction index along the fiber. The produced gratings are typically around 10 mm long. When an optical beam is injected into the fiber with the grating, the wavelength spectrum corresponding to the grating pitch will be reflected. The remaining wavelengths will pass through the grating undisturbed, as illustrated in Figure 3 [12].

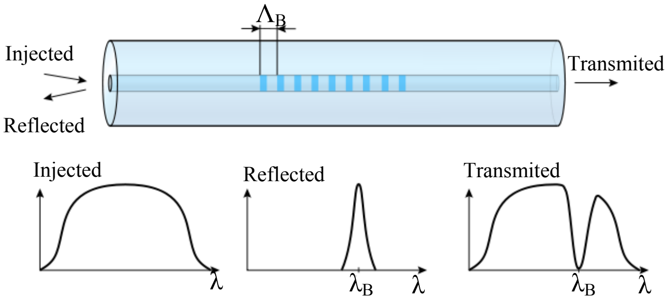

Figure 3 – Illustration of a Bragg sensor working principle.

Since the reflected wavelength depends on the refraction index associated to the fiber and on the diffraction network period, the Bragg wavelength will depend on the physic quantities that may change these parameters, while interacting with the fiber. Consequently, the Bragg sensors are intrinsically sensitive to temperature, axial and transversal deformation, and pressure. Through these sensibilities and especially by the axial deformation, the Bragg sensors can be used for other physical measurements. Unlike traditional resistance strain gages, FBG sensors are completely passive, offering inherent insensitivity to environmental induced drift and the possibility to obtain, simultaneously, temperature information. The main advantage to use Bragg gratings is it multiplexing potential [12]. Many gratings can be written in the same fiber at different locations and wavelengths tunes. This allows the creation of a strain map along a single fiber. However, since the gratings have to share the spectrum of the light along the fiber, there is a trade-off between the number of gratings and the dynamic range of the measurements on each FBG.

III. STRUCTURE FABRICATION

When thinking about a flexible sensing foil for automotive applications, the need for an "easy to apply" product becomes evident. In this context the sensing product should be handled without difficulties or at least, without friction or damaging of the included optical elements. For the FBG integration in the PVC carrier, the best approach is to insert the optical elements in the carrier matrix itself, lowering the friction and risk of damaging the optical elements. Furthermore, the insertion into the carrier matrix, should guarantee the best bonding of optical fiber with the PVC matrix and subsequently a better transfer of external stimuli from the host material to the sensor. For this purpose and considering the used manufacturing process, where PVC is spread coated as viscous plastisol over a rolling release paper, a suitable way to bring the optical fiber into the PVC core has to be designed.

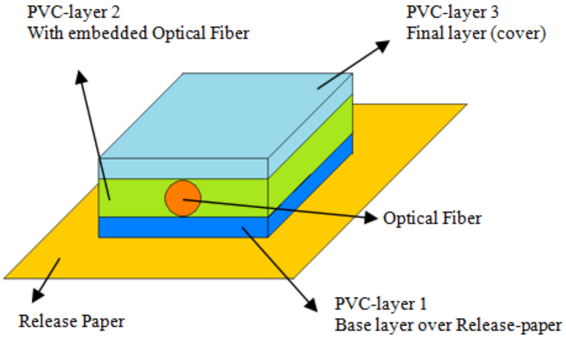

Figure 4 - Multi-layer structure for embedded optical elements in flexible PVC foil.

IV. STRUCTURE RESULTS AND DISCUSSION

Figure 5 shows functional prototypes produced as previously described. The polymeric foils had a Bragg sensor embedded in it. The fake-leather detail presented in Figure 5 is showed as an example of finishing detail that the surface can have in order to be meet the automotive interior design.

By visual inspection no damage was detected, being a good indicator of the fabrication process success. By touch, the fiber was not felt, sustaining the thought of a good integration level. The prototypes underwent two mechanical tests. One in which the continuous longitudinal deformation was measured while applying a constant load, and another in which the elongation was applied in incremental steps of 0.2 % (200 µm). The deformation rate was set to 16 µm/s. The optical response of the Bragg sensor was measured along the deformation.

Figure 6 shows the wavelength deviation along the deformation for the first test. As it can be seen, it has a linear behavior from 0.4 % ahead. The nonlinearity above 0.4 % was mainly due to initial elongation state of the sample. Notwithstanding this fact, the constructed sensing model with linear embedded optical fiber was able to sustain a stretching deformation of 1.62 %, which is equivalent to 1.62 mm displacement. At its maximal elongation value, the fiber registered an ultimate load of 9,691 N. At this deformation rate of 1.62 %, a wavelength deviation of 9.207 nm was measured and the curve slope of the present model is 0.6 pm/µε (picometer per microstrain).

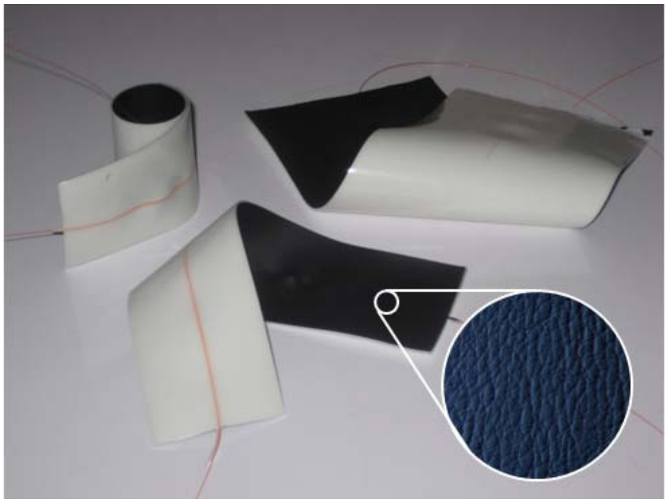

Figure 5 – Example of functional strain sensitive foils.

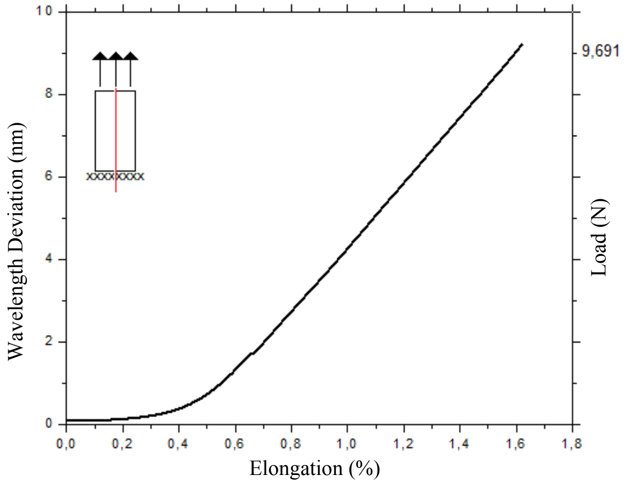

Figure 6 – Wavelength response to applied displacements

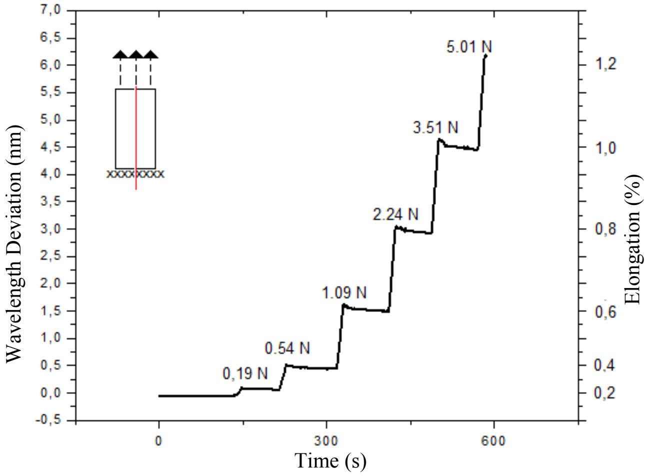

Figure 7 – Wavelength response to applied displacement steps.

In the second test, the linear deformation was induced in steps of 0.2 % (200 µm) elongation. After each elongation increment, the applied deformation load was kept constant during time intervals of approximately 60 seconds. During this segmented deformation, an optical signal was sent through the optical fiber and its wavelength deviation registered. Figure 7 shows for each deformation level a small decrease of the wavelength deviation. But after a few seconds, the line stabilizes, becoming almost totally flat. This small variation may be due to vibrations of the testing machine claw, since the sensing model has a high sensitivity as stated before. The preservation of an absolutely constant wavelength deviation is representative for a very strong bonding between the optical fiber and the PVC matrix, without any movement after an applied deformation.

V. CONCLUSION

The full integration of FBG sensors in common automotive covering foils was described. The flexible sensing model presented a linear behavior of 0.6 pm/µε (picometer per microstrain), measuring displacements up to 1.2 mm. The structure was also characterized by a full adhesion of the optical fiber sensor to the polymeric foil and also by the maintenance of the optical spectrum shape and amplitude during the load application, and repeatability, since it returned to its initial position. The Bragg sensor 10 mm length, allows the fiber layout to be fully customized, according to the desired smart structure. The sensors density is mainly defined by the needed sensor dynamic range and the interrogator system resolution. Integration of FBG based-sensors in PVC foils is demonstrated, with characteristics that allow its use in the automobile for strain mapping.

ACKNOWLEDGMENT

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REFERENCES

[1] J. H. Peretz, *et al.*, "Evaluating knowledge benefits of automotive lightweighting materials R&D projects," *Evaluation and Program Planning,* vol. In Press, Corrected Proof.

[2] W. J. Fleming, "New Automotive Sensors - A Review," *Sensors Journal, IEEE,* vol. 8, pp. 1900-1921, 2008.

[3] M. Linec and D. Donlagic, "A Plastic Optical Fiber Microbend Sensor Used as a Low-Cost Anti-Squeeze Detector," *Sensors Journal, IEEE,* vol. 7, pp. 1262-1267, 2007.

[4] "Plastics in the European Automotive Industry: State of the art and forecast," *Mavel Studies,* 2007.

[5] CES EduPack 2008 [Online]. Available: http://www.grantadesign.com/education/

[6] *Plastics & Elastomers Solutions – Omnexus*. Available: http://www.omnexus.com/

[7] D. S. Smith and P. R. Jackman, "Optical sensors for automotive applications," in *Automotive Sensors, IEEE Colloquium on*, 1992, pp. 2/1-2/3.

[8] H. C. Norm Schiller. (2004, December,1) Selecting Optical Detectors for Automotive Designs. *ECN*.

[9] P. Polishuk, "Automotive Fiber: Plastic optical fiber builds on MOST success," *Laser Focus World,* vol. 42, 2006.

[10] Wojtek J. Bock, *et al.*, "Fiber Optic Sensor for Automotive Applications," in *Sensors, 2004. Proceedings of IEEE*, 2004, pp. 248-251.

[11] B. Glisic and D. Inaudi, *Fibre Optic Methods for Structural Health Monitoring*, 2007.

[12] A. D. Kersey, *et al.*, "Fiber grating sensors," *Lightwave Technology, Journal of,* vol. 15, pp. 1442-1463, 1997.