Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 62 (2017) 386 – 390

www.elsevier.com/locate/procedia

10th CIRP Conference on Intelligent Computation in Manufacturing Engineering - CIRP ICME '16

Sensors embedded in surface coatings in injection moulding dies

Kristian Martinsen[a,*], Lars Tore Gellein[b], Klas M. Boivie[b]

[a]*NTNU, Department Technology, Economy and Management, Gjøvik, Norwa*
[b]*Sintef Raufoss Manufacturing AS, Trondheim, Norway*

* Corresponding author. Tel.: +47 99521849;. *E-mail address:* Kristian.martinsen@ntnu.no

Abstract

This paper describes results from EU FP7 project IC2 and beyond using surface embedded in surface coatings in thermoplastics injection moulding dies. Sensors where fabricated on the surface of inserts on a bridge tool for injection moulding of a component using Direct Write Thermal Spray. The sensors were encapsulated in an Al_2O_3 layers for electrical insulation and wear resistance. The data from the sensors was used to calibrate the FEM sensors for calibration of FEM process simulation and optimisation of conformal cooling channels on the production tool.

Peer-review under responsibility of the scientific committee of the 10th CIRP Conference on Intelligent Computation in Manufacturing Engineering

Keywords: Coating, Sensor, Injection moulding

1. Introduction

Any innovation, technological development and optimization of products and manufacturing where tools are used, are closely interlinked with innovations on the tooling as well as the product itself. The goal of the EU FP7 project 246172, Intelligent and Customized Tooling (IC2) was to combine Additive Manufacturing Technology, Surface embedded sensors, coating technologies and utilise these enabling technologies to novel competitive business models for tooling industry [1]. The project focused on tools for injection moulding.

1.1. Process monitoring and control of injection moulding

Pressure and temperature distributions within the mould cavities are some of the most critical parameters for injection moulding of thermoplastics components. Sensors embedded in the surfaces of the mould cavities can be a step towards including process data from the injection moulding tools. The signals from such sensors can be used to gain more process knowledge, which again can be used to calibrate FEM simulations, for in process control and data acquisition (SCADA) systems [1] and Cyber physical manufacturing systems [3], [4] (a.k.a. Industry 4.0). In-mould sensors are increasingly used and as Gao et. al. [5] writes: "*miniaturized and self-contained process sensors capable of monitoring both pressure and temperature near or right at the mold cavity become highly attractive to the injection molding industry for improved manufacturing process control*". The most common control strategies are however, still dependent on "*sensors installed outside of the mold to measure hydraulic pressure, screw position, and tie-bar extension"* [5]. The reason for this is both the cost of in-mould sensors and signal transmission wires as well as practical problems with placing sensors in the mould cavities and robust wire routing.

1.2. Data for optimising FEM simulations of injection moulding

Bridge tooling allows early stage pilot manufacturing and faster time-to-marked bringing a product to the market while the full performance tools are being produced and it might be beneficial to include sensors in the bridge tools. This enables process data acquisition in an early phase that can be used to confirm, adjust computer simulations [6] and to optimize the design of the full performance tools. Traditionally full performance tools have been massive blocks of steel sometimes with gun-drilled, straight, cooling channels. By the development of novel additive manufacturing technology, it is now possible to integrate conformal cooling and heating

Peer-review under responsibility of the scientific committee of the 10th CIRP Conference on Intelligent Computation in Manufacturing Engineering
doi:10.1016/j.procir.2016.06.048

channels in the tool [7]. Together, these channels make up an internal temperature management system permitting drastically reduced cycle times and improved quality by de-creasing warping, avoids sink marks etc. To fully integrate and optimize the positioning of these channels in the tool design, there is need for high quality in-data to make accurate simulations of the moulding process. Sensors that are incorporated in a prototyping and piloting phase could deliver enhanced analysis capabilities on tool, process and product behaviour such as thermal/mechanical stress, friction properties and inlet issues and offers an enhancement to virtual and numerical based simulation models that are of essential importance in the product development phase to ensure capability and robustness of the manufacturing processes. In this paper we describe a method for embedding sensors in coating layers and applied this on injection moulding bridge tool.

1.3. Mould surfaces

The material and the surface properties of the cavities of the mould dramatically influence the surface properties of the final product. Limited lifetime and loss of product quality of injection moulded components are often associated with a continuous decay of the mould by various wear and corrosion mechanisms such as abrasion from die and filler components, corrosion from aggressive gases and/or micro "explosions" formed during the moulding process, build up of residues from the plastic material, and fretting corrosion in connection with adjacent closing surfaces. However, advanced surface coatings may improve the mould surface properties, increase the wear resistance and enhance the lifetime [8], [9]. The tribological surface coatings used in tooling industry covers different coating types that are used in different tooling applications [10]. Examples are: (i) self-lubricant low friction coatings such as Diamond-Like Carbon (DLC), (ii) CrN coatings on surface parts directly in contact with the polymers, or (iii) high-energy nitrogen or chromium ion implantation to provide superior non-stick properties and en-hanced corrosion resistance of selected areas.

2. Surface-embedded sensors

As described can coatings bring benefits such as wear re-sistance and less frictional forces to the injection moulding process. The aim in the IC2 FP7 project was to merge three non overlapping worlds: (1) Manufacturing of injection moulding tools using AMT for conformal cooling, (2) coat-ings of tool three dimensional surfaces using Chemical Vapour Deposition (CVD), Atomic Layer Deposition (ALD), Plasma Enhanced CVD, and Physical Vapour Deposition (PVD) and (3) fabrication of MEMS sensors and the wiring to these sensors embedded in the layers. Figure 1 and 2 shows embedded sensors where the sensors are applied between layers of electric insulators. The top coating will typically be a wear resistance coating such as Diamond Like Carbon (DLC).

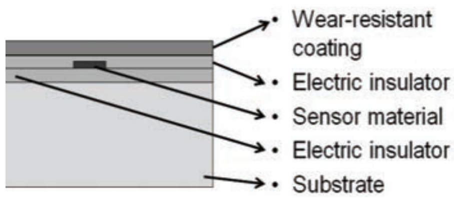

Fig. 1. Sensors embedded in coating layers

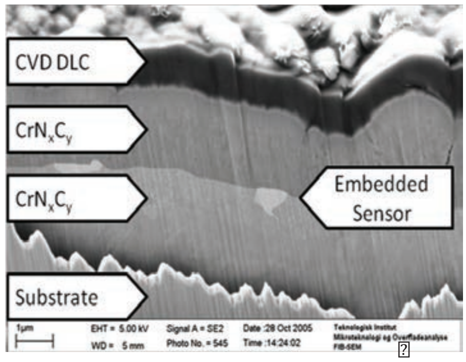

Fig. 2. Sensor embedded in coating layers

As the work in IC2 shows is one of the critical factor a pinhole-free electric insulator. Successful performance has been realized for Atomic Layer Deposition (ALD) combined with Physical Vapour Deposition (PVD) sputtering, and for sputtering combined with Chemical Vapour Deposition (CVD). The individual coating technologies are often not successful alone, and typically can a combination of ALD or CVD with PVD be the best solution due to a combination of line-of-sight limitations of PVD and the conformal characteristics of ALD/CVD based processes. To reduce the density of pinholes in the final film it is important to re-nucleate the film during deposition so the subsequent layer can cover defects in the coating [11],[12]. Furthermore was the task in IC2 to fabricate thin-film MEMS sensors on 3D (double curvature) surfaces rather than the con-ventional deposition of metal and isolation layers with photolithography processing techniques. These processes requires normally flat and smooth substrates e.g. silicon, quarts or glass wafers. Schonberg et al. [13] describes a method using a masking-and-coating approach to build a type T thermocouple thin film sensor, afterword covered by a wear resistant DLC coating. Schonberg et al. [14] reports from experiments in the IC2 project where K-type thermocouples were fabricated directly on the surface of a tool part using a Direct Write Thermal Spray process (DWTS) [15],[16]. DWTS enables additive manufacturing of multi-material patterns in 3D without any masking and is one out of may Direct Write technologies described by Hon et al. [17]. DWTS uses a miniaturised plasma gun on a robot arm. The process enables conformal fabrication of fine lines and structures suitable to build sensors and wires on the surface of mould cavities. The substrate will remain close to room temperature and a single layer can be down to 10 μm.