In-situ process monitoring and reliable cure control applied in RTM production of epoxy/carbon fibre parts

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SUMMARY

An innovative PC-based monitoring system has been used for the real-time sensing and control of composite manufacturing processes. The system comprises a durable non-intrusive electrical and temperature sensor, an electronic sensing system and the appropriate software for data acquisition and control. The sensors have been designed for the sensing of the complete process i.e. resin arrival detection, viscosity changes as well as material transformation up to the end-of-cure. The sensors' feedback is recorded and processed by the sensing system providing real-time material state information (viscosity, degree of cure etc.). Furthermore based on the monitoring feedback a control algorithm decides when to terminate the curing of each part leading to shorter and more reliable production. This monitoring system and 2 sensors have been installed at Technica Plastika industrial site and used successfully for the first time in the production of epoxy/ carbon fibre parts using closed mould injection (RTM). Based on some statistical data from the production acceleration up to 36% was achieved in the curing cycle whereas the production rate was increased 80%.

1. INTRODUCTION

In liquid composite moulding there is a real need for durable non-intrusive sensors that not only inform about resin arrival at some points but provide complete information of what is happening in the cavity for real-time control and for quality control purposes. As the installation and operation of such sensors is not an easy task in real production environment, it is very important that these sensors are robust and durable.

Previous work (Pantelelis et al. 2006) has shown that the cure process of thermosets in composite materials processing can be followed in real-time and *in situ* using the dielectric cure monitoring method. The importance of this approach is that the dielectric signal can provide reliably and in real-time all the important process milestones: the minimum viscosity, the gel point and the vitrification time (Pantelelis and Maistros 2006). The ultimate target is to interpret these data and provide intelligent and optimal process control capabilities. To achieve the optimal process control, the electrical and temperature measurements should be combined with models of thermoset cure. These mathematical models convert the time-temperature profile of cure process environment to the resin viscosity η and the glass transition temperature T_g and reflect the kinetics and the molecular structure formation in the thermoset resin matrix. These models can be run either online or offline to provide the optimal process control capabilities in composite materials manufacturing (Pantelelis 2005).

In principal similar performance can be achieved by measuring the electrical resistance of the reactive resin using DC. In the literature several point sensors and DC amplifiers have been used such as Tajima (1982), Schwab et al. (1996), Danisman et al. (2006) but the first commercial system has been recently available. At the present paper some new developments on this new DC sensing system will be presented together with an example on how to take advantage of this information in liquid composite moulding.

2. PROCESS MONITORING USING DC SENSING

In the dielectric sensing a series of sinusoidal voltage or current excitations are applied to the electrodes of a sensor which are in contact with the material under investigation and the feedback which is measured and processed provides an indication of the state of the material under investigation. Although significant effort has been devoted for more than 25 years in this technology no significant industrial level applications exist. On the other hand Synthesites has spent considerable effort in developing the DC sensing i.e. applying a steady signal to the sensor's electrodes for industrial applications. Although the basic idea is very old e.g. Tajima (1982) for liquid materials with relatively low resistance no significant progress was presented until recently in extending this idea to full range measurements. Synthesites managed to develop a durable sensor and a high-resistance versatile electronic system capable of monitoring the full transformation of a thermoset resin i.e. from very low viscosities at high temperatures to full cure where the resin resistance ranges from 1 MΩ up to 1TΩ. Comparisons of the Synthesites system with dielectric systems as well as with theoretical results showed that superior measuring quality is achieved especially at the end of cure area (fig.1), faster with very simple hardware and CPU requirements.

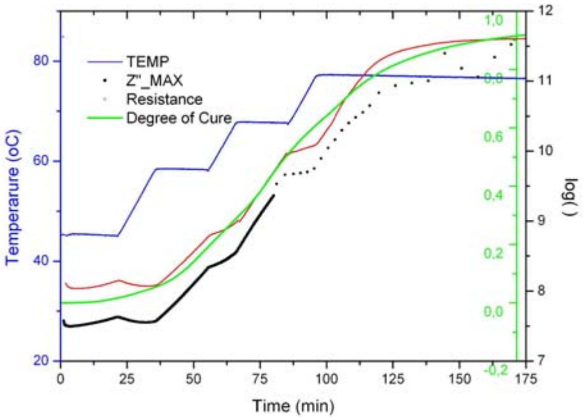

Fig.1. Comparison of theoretical (degree-of-cure) and experimental (dielectrics (Z''max) and electrical resistance measurements) of the cure of an epoxy system.

Besides the end-of-cure detection the system can be used for monitoring the viscosity of the resin in the cavity in order to verify the onset of viscosity rise and/or the quality of the resins. For example in fig.2 a fresh and an aged monocomponent epoxy resin has been measured simultaneously with a viscometer and the DC sensing where it is evident that the viscosity and the resistance of the aged resin drops less at the injection temperature and rises quicker than the fresh resin.

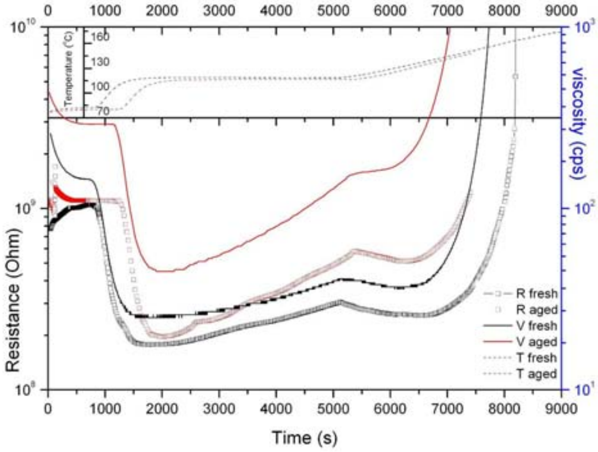

Fig.2. Comparison of viscosity and electrical measurements for curing of fresh and aged RTM6.

3. RESULTS

To verify the performance of the DC sensing in "real" industrial environments two sensors were installed near the injection and the venting gates of an RTM tool used for the manufacturing of epoxy/ carbon fibre reinforced sandwich parts (fig.3 left). Both sensors were monitoring resin resistance and temperature and their feedback was recorded (fig.3 right) and used for quality and process control purposes. During the trials the sensors did not receive any special treatment from the operators and did not show any problem due to the existence of carbon fibres in the mould cavity.

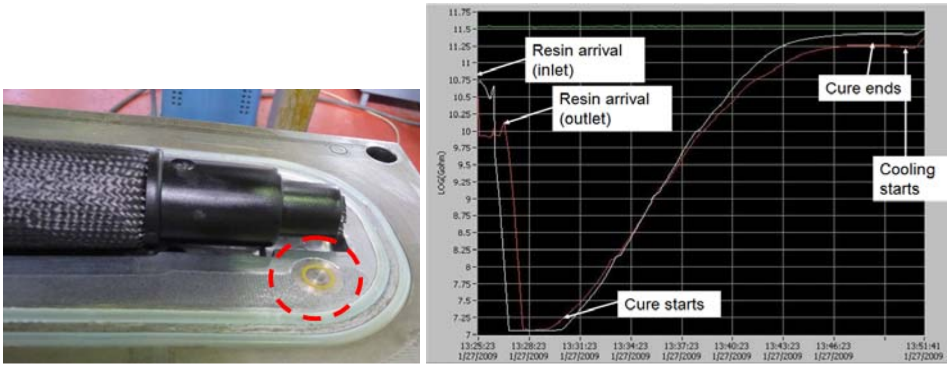

Fig.3. Flush mounted sensor at the technical area near the inlet gate (left) and screenshot of the real-time the detection of the processing milestones (right).

At the initial trials without control the mean curing time was 1980 s (fig.4) while with control a 36% reduction of the curing time (mean 1267 s) was attained by increasing 5°C the injection temperature and by ending heating suitably sooner or just 30% acceleration (mean 1408 s) when only the shorter ending was implemented.

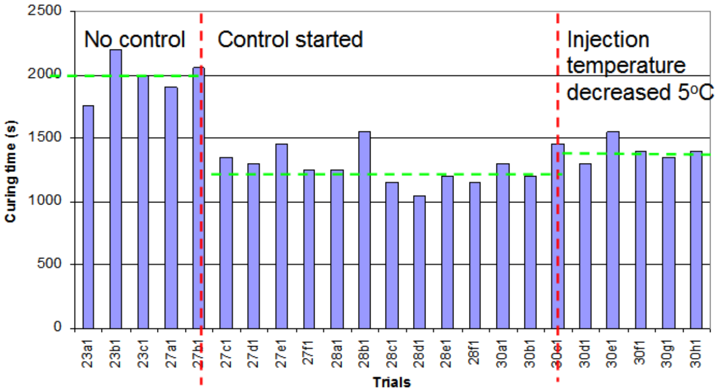

Fig.4. Curing times for the RTM production before and after cure monitoring and control shows acceleration from 30 to 36%.

4. CONCLUSIONS

An innovative process monitoring system has been used for the real-time monitoring of cure and viscosity in a real industrial environment. The system demonstrated exceptionally stable measurements and robustness without requiring any special treatment from the production staff. The installation of the sensor in the tool was easy and the interpretation of the data was straightforward due to the simultaneous temperature measurements. The development of a simplified control strategy that was taking advantage of the feedback from the process monitoring system led to a 30 to 36% decrease of processing time allowing for an overall increase in the production rate from 4-5 parts per shift to 8 parts per shift.

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