Reactive molding: From simulation to reality

ABB produces a wide range of medium- and high-voltage electrical equipment, including switchgear, voltage and current transformers, sensors and bushings. Several different reactive molding technologies based on thermosetting materials like epoxy resins are used in manufacturing these products, and these are key skills in many ABB companies.

ABB has now developed a simulation tool to further increase product quality by identifying production problem sources. Moreover, the tool can be used to optimize production process parameters, resulting in lower energy consumption and a significant reduction in product cycle time.

Getting into shape

Automated Pressure Gelation (APG) – the most common reactive molding process used for high-volume production – can be characterized by short molding cycles (minutes) and high accuracy. Any shrinkage of the molded part during gelation is compensated for by continuously injecting liquid mixture into the casting mold.

In APG, two or more liquid reactants are mixed with additional components. After homogenizing and degassing, the mixture is injected into the heated mold. Polymerization (curing) of the material generates additional heat and the component hardens into its desired shape. This is followed by de-molding and secondary heat treatment.

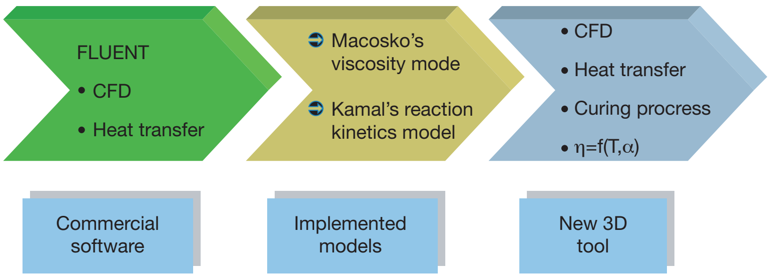
Reactive molding problems

The long product development time (one to two years), the need for external expertise and the relatively low initial product yield means that reactive molding technology can be a bottleneck during the manufacture set-up. And even when things are up and running, the APG process can encounter problems, such as air voids, incomplete filling, premature gelation, wrong curing propagation, high temperature gradients and local overheating. Mold-making and process optimization tend to rely a lot on practical experience and time-consuming trials.

To overcome these problems, ABB Corporate Research scientists from Poland, Finland and Germany have developed a fully three-dimensional simulation approach that increases our understanding of thermoset behavior during the manufacturing process.

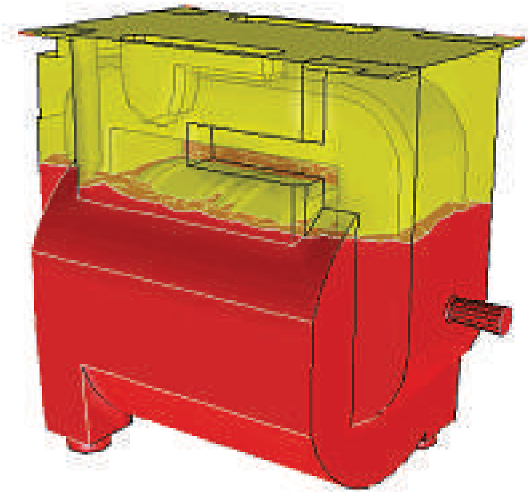
The simulation solution

Early on, FLUENT, a commercial simulation package, was identified as an ideal platform upon which to build specific solutions that successfully model both process stages, namely filling and curing. To model the reactive system, viscosity and reaction kinetics, models were implemented in the software as user-defined functions (Fig.1). This means different base materials can be accommodated.



1 Simulation tool development

This approach was very challenging, bearing in mind the fact that, so far, only 2D and 2.5D modeling has been successfully performed (2.5 D is 2D with planes raised into the 3rd dimension). For complex component shapes and large volumes of resin, such simulations do not give satisfactory results, which explains



2 Filling stage – voltage transformer

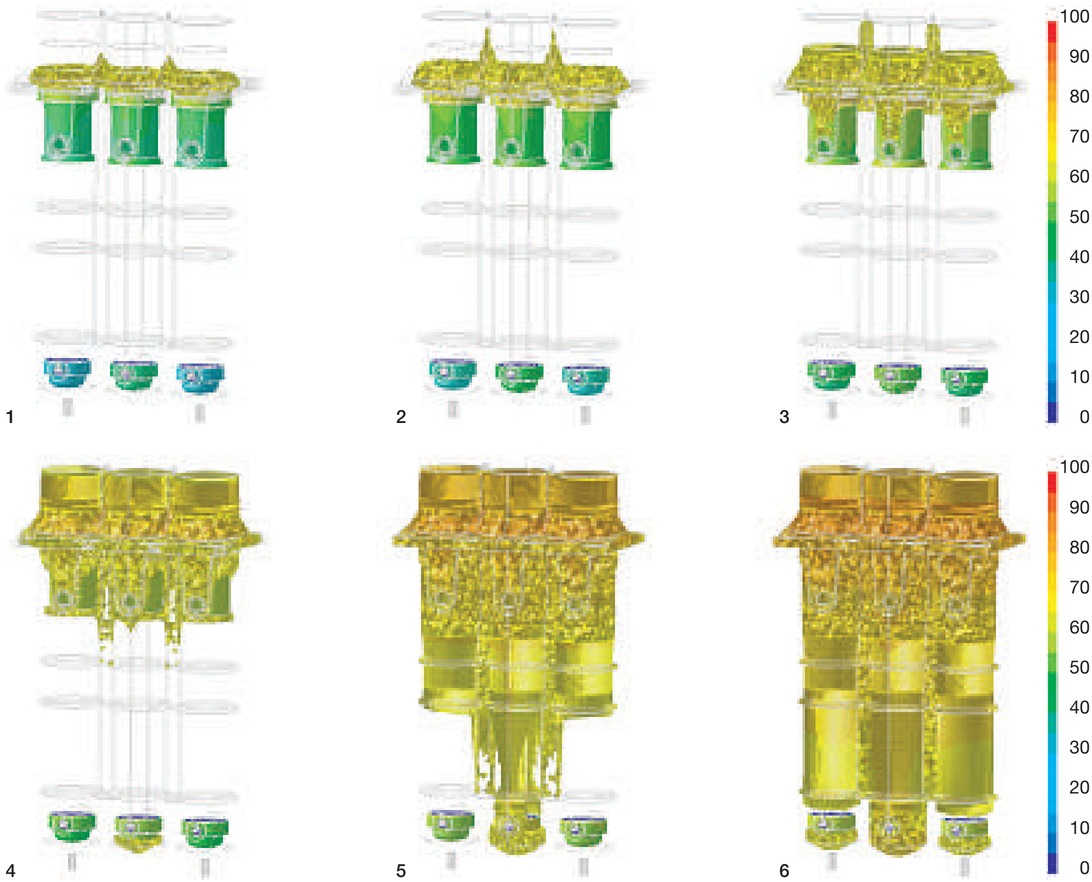
their rare use in ABB. What is more, the 2D or 2.5D approach is poor on mold filling and flow patterns.

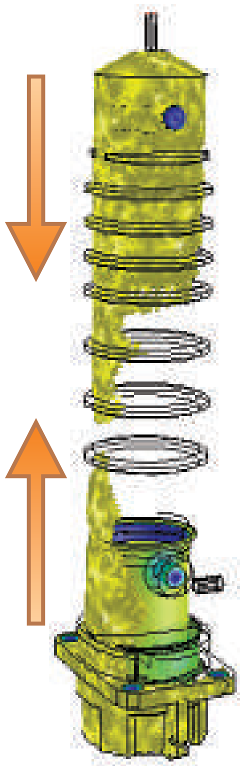
In contrast, the new ABB simulation tool gives product designers and production engineers a handle on data, such as mold temperature, inlet mixture temperature and feed pipe location, all of which influence the filling and curing process and allow the elimination of many of the defects mentioned earlier.

Pour away

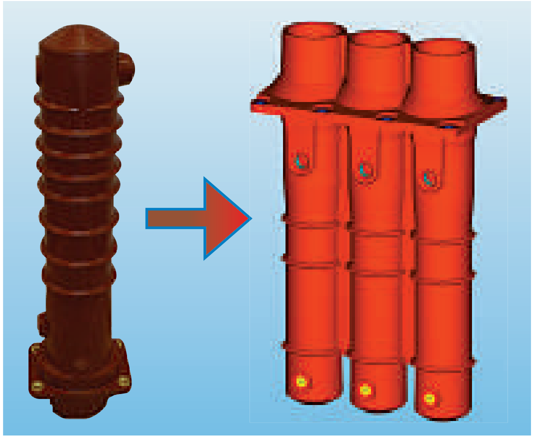
Some half-dozen ABB companies and their products were involved in the project, and in all cases potential problem areas were identified and improvement recommendations made. Different parameters, such as temperature, velocity, pressure and degree of curing, were observed and various visualization methods employed. For example, in Fig. 2 the filling stage is presented for a simulated case. The red color denotes the resin

3 Curing front propagation





4 Two curing fronts in a simple fuse canister



5 From a single to triple fuse canister. New developments are supported by reactive molding.

flowing into the mold cavity. In this way, it is possible to determine any casting problems, such as non-complete filling or pre-mature gelation, and change process parameters or the feed pipe location.

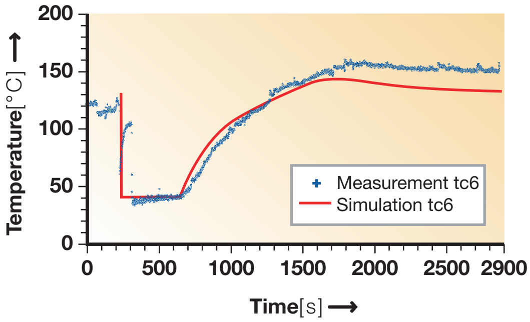
Some of the most useful information obtained from the 3D simulation concerns curing front propagation. Fig. 3 illustrates a gelation phenomenon in a triple fuse canister. The material that is already cured (solid) is shown. It can be seen where polymerization of the resin is initiated and how the curing front propagates. This information is vital to the process technologists as it enables them to set parameters that will prevent problems such as void formation or multiple curing fronts coming together (Fig. 4).

Product highlights

The tool has attracted a lot of attention from ABB companies using reactive molding technology in their products. One product that provided a particular challenge was a fuse canister for ZX0 switchgear. The results of the simulation turned out to be very positive and the tool was consequently employed in the development of a completely new product – the already mentioned triple fuse canister (Fig. 5). All process parameters and modifications to the design are set using the simulation approach.

The KEVCY 24 SE1 integrated combined MV voltage and current sensor (ie, combi-sensor) is another new product that has benefited from having the simulation tool applied in an early stage of product development. Another excellent example is the KEVCY 24 RE12 MV sensor: during production start-up, use of simulation-based analyses contributed significantly to an improvement in yield from about 10% to 95% in just a few months.

6 Comparison of simulation and experiment



Experimental verification

What results can we expect from taking physical measurements during a molding process and comparing them with simulation predictions? Is the simulation experimentally verifiable?

To answer this question, temperature measurements were carried out on a voltage transformer during and after filling. To this end, a number of shielded NiCr-NiAl thermocouples (type K) with an external diameter of 1 mm were fitted at different locations inside the mold.

It was shown that there was good agreement between the computer modeling and experimental measurements (Fig. 6). This confirmed the suitability of the developed simulation tool for modeling reactive molding processes.

7 Experiment versus simulation: two resins with different colors

Additional verification was obtained for the filling stage. A full-scale experiment on a single fuse canister was performed using resin with two different colors. First, the dark resin was injected into the mold and then, halfway through, the lighter resin. A comparison of the simulation and experimental results again shows good agreement (Fig. 7).

While the simulation tool can be said to have definitely proven its worth, a further development program is currently under way to make it even more powerful. This targets the simulation of chemical shrinkage and thermal stress. The way things look, that's not likely to be the end of the story, either!

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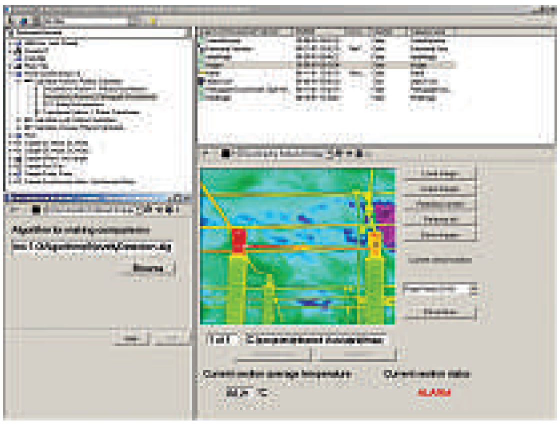
Industrial^{IT}-powered infrared diagnostics

Researchers at ABB Corporate Research have recently developed a pilot implementation of an Industrial^{IT}-based tool for substation equipment diagnosis using infrared measurements - Advise^{IT} Infrared Assistant.

The interaction of processes – and the systems that guide them – through the exchange of dynamic, real-time information is what ABB calls Industrial^{IT} (IIT). In its simplest form, IIT could be characterized by an open control system that automatically configures and re-ranges hundreds of plant instruments to the real-time needs of a new production run. But it could be much more. Imagine, for example, that each physical plant device was accompanied by a dynamic, living software entity – carrying with it not only configuration data but control software, purchase and cost information, maintenance records, mechanical drawings, and networking information. Next, imagine that the same approach could be applied to products – endowing each batch, barrel, or box with a dynamic set of real-time characteristics.

Now, consider the impact if distributed plant devices could inherit functionality from the environment in which they were placed. New devices would be configured not by a host control strategy, but as a direct result of the business setting in which they were deployed. Process transmitters and valves would inherit the range information required for the current 'recipe'. Motors and drives would adjust their control setpoints as a function of current line speeds.



ABB's powerful enterprise architecture, called Aspect Objects™, considers the myriad of enterprise objects (plant devices, machines, materials, products) as the building blocks that make up a total business scenario. Although the various objects and their associated software may reside on multiple networks or computers, each object carries with it an integral collection of characteristics or aspects (configuration, efficiency, maintenance status, mechanical and electrical drawings, etc). A click on any object icon quickly offers up a wide range of context-sensitive, real-time information.

Advise^{IT} is the name given to the IIT product suite of tools that facilitate evaluation of process parameters, product or equipment status. This is where substation diagnosis comes in.

Basic IIT information (technical specifications, CAD drawings, etc), encapsulated in an aspect system representation, is now enhanced with a set of dedicated diagnostic aspects. These aspects carry information on measurement methodology ('what and where') and interpretation (eg, acceptance limits) that are both object- and diagnostic technology-dependent.

Infrared thermography requires knowledge of the object's inner workings on the one hand and thermal pattern recognition on the other. While basic aspects may provide the former, Advise^{IT} Infrared Assistant delivers the latter, offering an extension which makes an IIT-enabled object 'thermo-diagnostics-ready'. This ranges from a set of reference images representing a normal condition, through a list of critical zones or subcomponents, ready to use as practical guidance at the time of inspection, to dedicated processing algorithms specific for that particular object and source of diagnostic data.

For example, past research in this field produced a thermal trend analysis algorithm (novelty detection) for HV disconnectors that can be 'hooked' to IIT-enabled disconnector code for immediate use by maintenance personnel once measurement data become available.

As IIT aspects are portable to other objects, the 'infra-extensions' can easily be transferred to make existing objects ready for infrared diagnosis with some minor effort in coding settings, such as acceptance limits.

Being generic, the solution has a wide scope of potential applications in general condition monitoring, two of which are partial discharge measurement and vibroacoustics.

The Advise^{IT} Infrared Assistant demonstrates how the Industrial^{IT} aspect-driven environment allows the machines themselves to be capable of conveying the relevant diagnostic know-how and settings to the maintenance personnel.