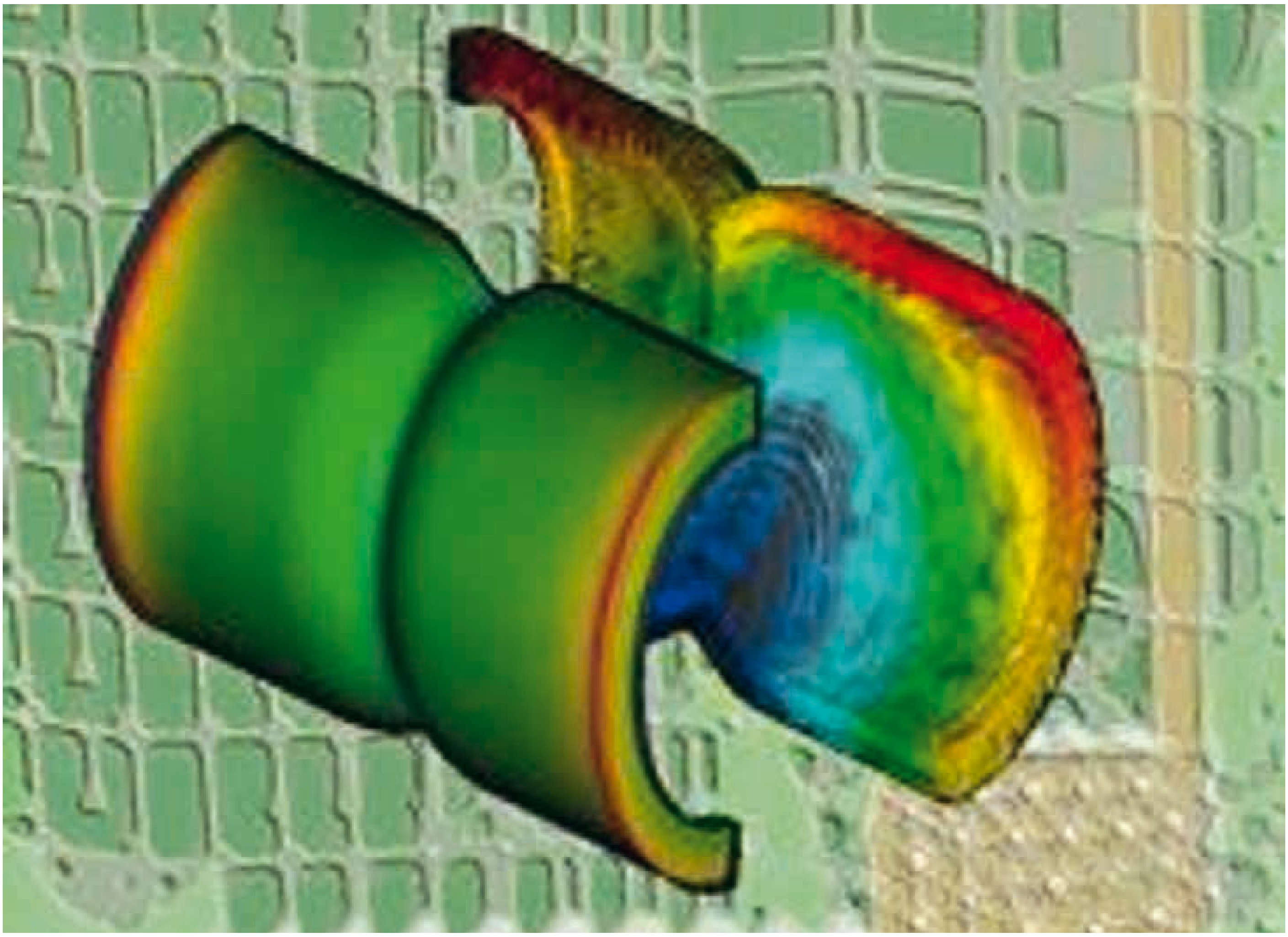


Molding the future

Polymers processing enhanced by advanced computer simulations

ROBERT SEKULA, KRZYSZTOF KASZA, LUKASZ MATYSIAK, LUKASZ MALINOWSKI, DARIUSZ BEDNAROWSKI, MICHAL MLOT, GERHARD SALGE – Due to their excellent electrical, thermal and mechanical properties, polymeric materials are the principal insulating materials used in many ABB power products. Because of the shape complexity and wide range of parameters used in manufacturing technologies, there can be product quality challenges. For example, air voids, incomplete filling, premature gelation, incorrect curing propagation, local overheating, cracks and deformations may appear in the insulation. However, through advanced computer (numerical) simulation tools, ABB maintains the highest quality control of its products, and minimizes the development time of new products. These simulation tools allow engineers to explore thousands of design alternatives within very short time periods, leading to improvements in performance and design quality, and reducing the time required to bring a product to market.

1 Results from simulations of epoxy casting and polymerization process

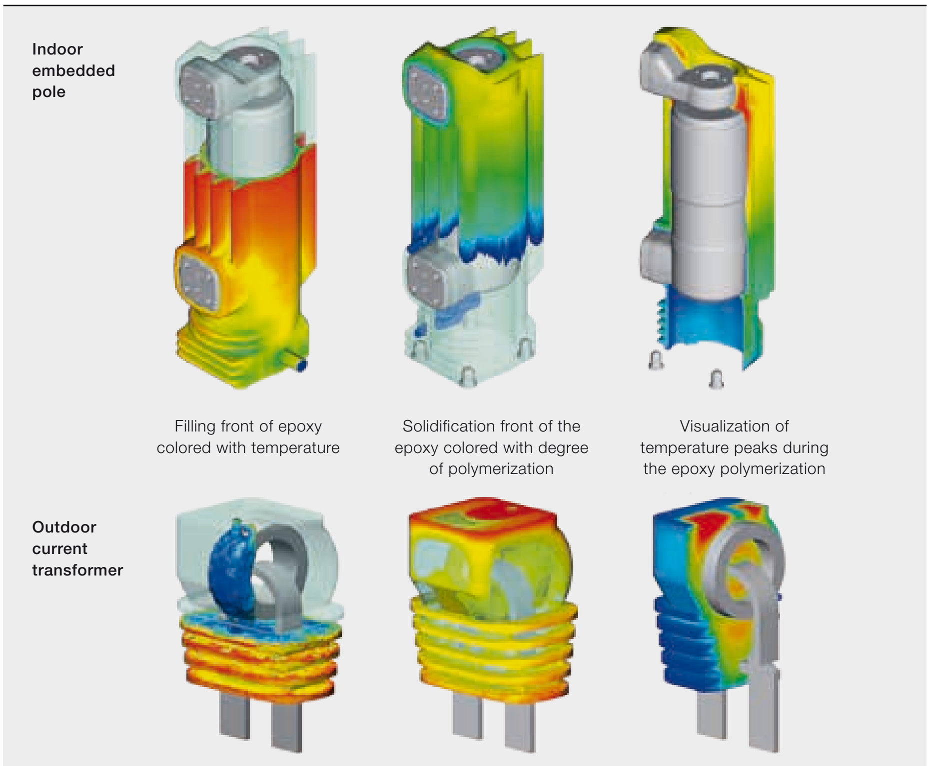


ABB uses advanced computer simulations in all of its polymers processing technologies, including reactive molding, injection molding, and silicone molding.

Epoxy casting

Epoxy resins are the principal insulating material used in manufacturing ABB's medium- and high-voltage products. The complex manufacturing process, referred to as reactive molding, includes casting, gelling (solidification) and cooling. By using a multiphysics approach that brings together advanced computer simulations of fluid flow, heat transfer, mechanical deformation and stresses, more accurate results are achieved and engineers are better able to follow and control the manufacturing process.

They can observe the mold filling with epoxy resin, the material transition from liquid to solid state, temperature distribution with temperature peaks caused by exothermic chemical reaction, shape deformation during the cooling and related buildup of stresses [1, 2] → 1. Detailed analysis of the obtained results helps in selecting the best process parameters. Maintaining the right processing temperatures and minimizing the residual stresses are the key factors that determine the final product quality and reliability.

ABB has also developed a Web-based epoxy casting simulation tool that offers fully automated calculations [3]. The calculations can be performed directly by design or process engineers with no numerical modeling background. The mesh generation, simulation setup, calculations and other steps are done automatically based on input variables like model geometry, selected materials and process parameters. The tool generates a report with a summary of the results that can be used to analyze the process regarding its quality and efficiency.

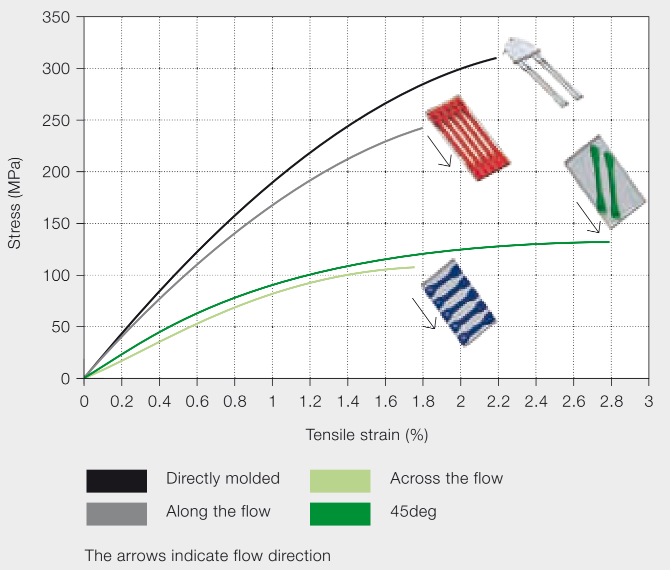
> To maximize the composite potential in the development of its thermoplastic components ABB uses advanced simulation.

Thermoplastics injection molding

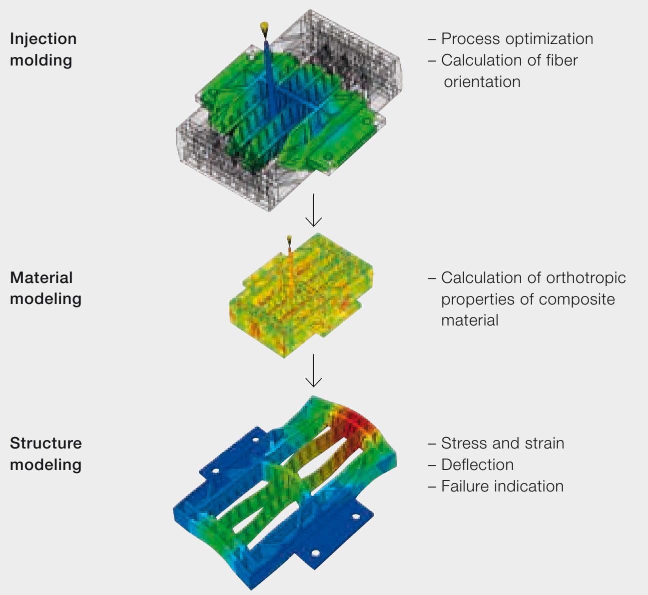
Thermoplastic polymers, used predominantly in ABB low-voltage products, are distinguished from epoxies and other thermosets by their ability to be melted and molded when heated above certain temperatures, returning to a solid state upon cooling. Injection molding is the most common processing method for thermoplastics. Hot, melted polymer is injected at high speed (up to hundreds of cm^3/s) at high pressure (up to 2,000 bars) into a cold mold cavity; while the polymer is cooling, the pressure is maintained by the injection unit in order to compensate for shrinkage. When the polymer temperature is 20 to 30 °C below the solidification temperature enough mechanical strength has been gained so that the part can be ejected. Production cycle time depends on wall thickness (starting from 0.5 to 6 mm) and usually takes from a few to around 100 s. Part and mold design is very challenging because of the complex phenomena occurring during thermoplastics processing – eg, shearing, viscous heating, crystallization, orientation,

Title picture
Optimization of a sample component achieved with injection molding simulation.

2 Comparison of tensile test results for polyarylamide 50 percent glass fibers in the case of different orientation of short fibers



3 Simulation approach for short fiber reinforced thermoplastics processed by injection molding



Advanced computer simulations are conducted in order to optimize each part and mold design before mold fabrication.

cooling and undesired deformation (warpage).

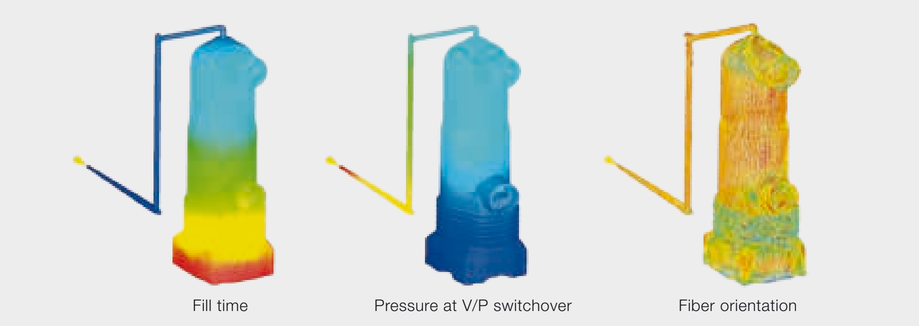
Advanced computer simulations are conducted in order to optimize each part and mold design before mold fabrication. The computer simulation tool allows analysis of all the processing stages: injection, packing and cooling (ejection time and its impact on heat distribution in the mold is even taken into account). The simulation model considers all the essential components of the injection mold, such as part cavity, cold or hot runner system, part or mold inserts, cooling circuits, and mold venting if necessary. Computer simulations help evaluate the quality of the injection stage in terms of filling profile, flow stagnation, premature polymer freezing or location of weld lines and air traps. During the packing and cooling stages the efficiency of shrinkage compensation is evaluated so that the correct selection of a cold gate cross-section can be made. The shape of the final part is also modeled by taking into account warpage caused by the polymer shrinkage, uneven cooling and material orientation.

The software used for injection molding simulation includes a database with over 6,000 predefined thermoplastic materials, which can be used for material specification – eg, pressure-volume-temperature (PvT), viscosity as a function of temperature and shear rate, and thermal and mechanical properties. The software also handles processes like gas-assisted injection, injection compression, co-injection and fiber-reinforced materials.

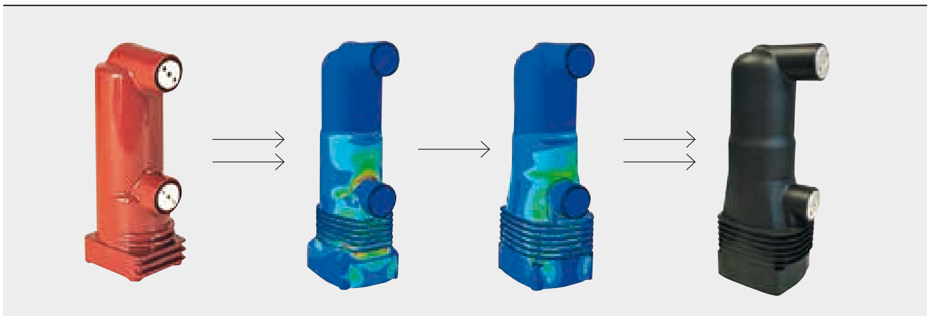
Thermoplastic composites reinforced with short glass fibers are also often used as insulating material because of their excellent mechanical and thermal properties. Introducing these materials into a product is challenging because the short fibers in a polymer matrix are aligned in flow direction during the injection-molding process resulting in anisotropic material properties. The highest stiffness and strength is measured in the direction of material flow during molding, while the transverse performance could be only 35 percent of material datasheet values (based on measurements for polyarylamide reinforced with 50 percent glass fibers) → 2.

To maximize the composite potential in the development of its thermoplastic components ABB uses advanced simulation → 3. The first step of the simulation process is to gather information on fiber distribution. Material properties of polymer matrixes and fibers are defined separately in the material modeling software, which calculates the resulting mechanical properties of the composite. These values are then used by a structural simulation package to calculate product response under applied mechanical load. Estimating the critical load that can be carried out by the composite material becomes feasible with stress- and strain-based failure indicators [4, 5].

4 Simulation results of injection molding process of thermoplastic embedded pole



5 Mechanical optimization of thermoplastic embedded pole structure



The dielectric performance of the design is checked with the simulations of the electric field distribution.

From epoxy to thermoplastics

Thermoplastic materials have been widely used in low voltage products applications. With the increasing capabilities of engineering thermoplastics, they are also being considered as a replacement for thermoset epoxy insulation for higher voltage level products. The mechanical properties of engineering thermoplastics are much better than of epoxies, with significantly higher stiffness and several times higher mechanical strength. The dielectric strength of the thermoplastics can also be superior. These strengths allow for significant reduction of the product weight and environmental impact.

ABB's PT1 embedded pole is an example of switching from epoxy to thermoplastics in ABB's medium voltage applications. Changing the insulation material results in a weight reduction of more than a factor of three while gaining superior mechanical performance. The material change reduces CO_2 emissions in the product life cycle by more than 50 percent [6]. All these improvements have been achieved by using advanced computer simulations.

Injection molding of thermoplastics is better suited for thin-walled parts in contrast to the bulky structures of epoxy components. Therefore when a material change needs to be made for a medium or high voltage product, a complete redesign of the product is needed. The first stage of a redesign is to create the design ideas and then a draft design of the plastic part. Then the evaluation and optimization of the concept is carried out with simulation tools. In the mechanical analysis all the load cases to which the product is subjected during its operation are modeled. In parallel, the manufacturability of the part is verified with simulations of the injection molding process → 4. The dielectric performance of the design is checked with simulations of the electric field distribution. Based on simulation results, modifications are introduced to the design and the next cycle of simulations is started. Based on the final results, the prototype of the part is manufactured and subjected to all tests required by standards.

Computer simulations allow engineers to look inside the injection mold for a complete picture of how the silicone rubber is processed.

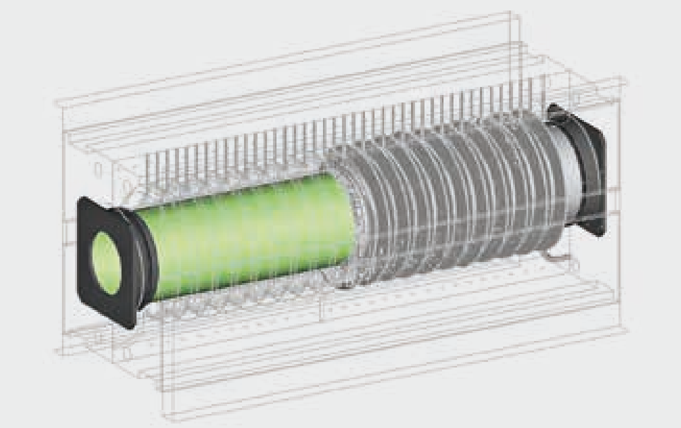
With ABB's thermoplastic embedded pole, such an approach allows for a 50 percent decrease of the maximum stress level in the part → 5. By using the injection molding simulation the process settings are optimized and the material pressure in the mold cavity is reduced, which is important in this application as the overmolded vacuum interrupter was designed for low pressure casting process. With the computer simulations both the design of the thermoplastic embedded pole and its manufacturing process were optimized.

Liquid silicone rubber processing

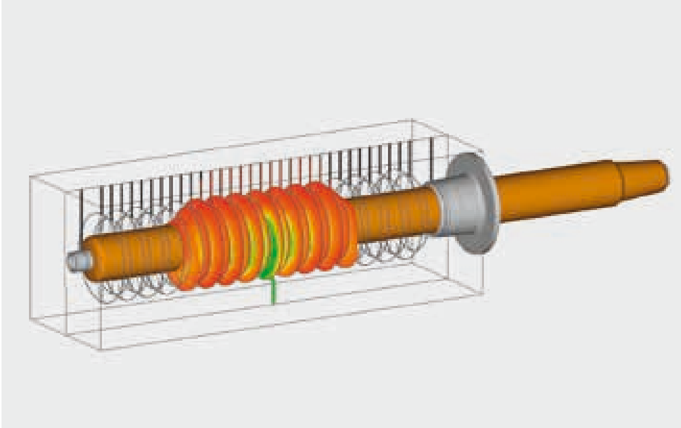
Silicone molding is another processing technology extensively used for producing electrical insulation in medium- and high-voltage power products like surge arresters, bushings, insulators and cable terminations. The excellent properties of silicone rubbers include high chemical and thermal stability resulting in the material hydrophobicity, UV stability as well as good flashover and erosion resistance [7, 8].

Another factor influencing the properties of the silicone insulation is the material processing during the insulation manufacturing stage.

6 Flow pattern and curing for HV silicone insulation



6a Flow pattern of silicone during mold filling



6b Course of curing process of silicone

One of the possible threats connected with silicone molding is too high temperatures during the process that can cause degradation of the material properties. Good temperature control is even more important when taking into account the exothermy (heat generation) during the silicone curing, which might lead to creation of local hot spots. Besides that too severe temperature conditions can result in premature gelation of the silicone rubber and, consequently, in incomplete filling of the mold. Finally, incorrect design of the injection and ventilations systems can create air gaps during the mold filling, creating partial discharges in the operating product.

Computer simulations allow engineers to look inside the injection mold for a complete picture of how the silicone rubber is processed [9, 10]. For example, the silicone flow pattern, pressure growth, temperature field and silicone cure degree can be observed over time → 6. These results can be further used to recognize the potential problems connected with product design or its manufacturing process. Computer simulations can be applied to work out the improved product design and production process in shorter time periods and with lower investment costs.

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Further reading

eRAMZES – Breakthrough in advanced computer simulations, *ABB Review* 01/2013