Development of Easy-to-Use Die Design Programs for Zinc Die Casting

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Good surface finish and soundness require elimination, or at least minimization, of hot spots and other thermal patterns that cause undesirable freezing sequences in the die. These are influenced by the location of cooling lines, heating cartridges, thickness of casting walls, and the gate location. Proper location or sizing of these features can now be determined by an inexpensive and easy-to-use PC-based 3D computer model called DIANA (DIe casting ANAlysis), avoiding the need for actual casting trials and reworking of the die if casting quality is unsatisfactory.

A related computer model for the prediction of shape-dependent shrinkage is currently being investigated As net shape requirements become more commonplace and precision more stringent, the influence of shape-dependent shrinkage becomes more important. Many die designers still use the old rule that a zinc die casting will shrink 0.07% on cooling, and size the die casting accordingly. However, free contraction during cooling occurs only when the casting is unconstrained in the die cavity. Features such as gates, bosses, and cores prevent free contraction and may actually result in apparent expansion of the casting (relative to the cold die dimension) at certain locations. Reworking of the die is required if casting dimensions are not within required tolerances. Accurate prediction of shape-dependent shrinkage would allow first-time machining of the cavity to dimensions that take this effect into account.

Goals: Simplicity, Speed, Accuracy, Economy

The goal of this development program was to produce a fully three-dimensional computer model capable of addressing the above problems that could be run on a personal computer, that would begin to provide predictions normally within a working day, and that would be as inexpensive as possible. These objectives have been achieved for the thermal model but require further practical numeric validation for the shape-dependent contraction model. The thermal modeling can be performed in two ways, employing either a fast simulator using a rule-based lattice computation method or a more involved finite difference method. The shape-dependent contraction model uses a finite element method. Because the latter two involve more computer calculations, they may require more than a day to run; however, their simplicity from the user's viewpoint approaches that of the fast simulator.

Generating the Shape

If the die casting has been produced on a CAD system, its shape can be imported directly into the DIANA program if it has been produced on any system-e.g., Autocad, Pro-Engineer, CADDS-5X, or DUCT-- capable of supplying stereo-lithography files.

If the casting shape is not available on a CAD file, using the program's own solid modeler, the shape is rapidly produced by "drawing it" with a cube generator. The cube size is set as fine as necessary to produce casting features in sufficient detail. Up to 2,000,376 cubes can be used to represent the 3-D casting/die geometry. The positions of any cooling channels or heating elements also can be included. This method of producing a casting shape for analysis would take about 1 to 3 hr to set up for a casting of typical complexity.

Following generation of the shape, it can be statically viewed from six different angles, or dynamically viewed from 36 angles, using an animation program.

Thermal Modeling by Rapid Simulation

The DIANA rapid simulator uses the casting shape, cooling/heating line location, and other information provided in the above step to determine the nature of the temperature distribution that develops over the surface of the die cavity and core faces during steady-state die casting cycles. The freezing pattern in the casting resulting from this temperature distribution is then determined. The outputs are color-coded images, with the colors representing either the temperature distribution on the die and core faces or the progress of freezing of the casting. The times and temperatures are not numeric in value, only relative. Nonetheless, most die casters agree that this description is sufficient to provide considerable aid in thermal design of the die, especially with regard to location of heating and cooling features.

The output of this analysis can be manipulated in several ways. The first is that the solidification simulation can be stopped at any percentage of casting solidified. This is helpful in predicting when shrinkage and surface defects caused by solidification problems may occur. The die face temperature distribution can be mapped onto the face of the casting, helping to identify how die thermal features may influence surface quality. Also, "slicing" of the casting by three orthogonal planes can allow viewing of the successive positions of the freezing front in the casting. Finally, an "X-ray view" of the last regions to solidify can be obtained, as these often lie within thicker sections. An additional routine allows calculation of casting weight.

The advantage of the rapid simulator is that it is quick to use, requires no data input for material properties and boundary conditions, and takes only 8 MB of computer memory. However, only qualitative results can be obtained from the color-coded temperature and freezing sequence post-processors.

Thermal Modeling Using Finite Difference Model

Increases in speed and memory capabilities of personal computers during recent years have facilitated development of several three-dimensional numeric models. The DIANA program also uses an alternative three-dimensional quantitative thermal model that actually solves the equations governing conductive heat transfer in solidification. It is a finite difference model; temperature and materials property data known at any time is used to calculate a new temperature field at a later time.

The starting point is the same casting shape used for the rapid simulator. This model requires actual material properties which are kept in a data base and can be changed as required. Properties of the casting metal, die, cooling water, and air also are assigned to appropriate portions shown on the screen, and location of the gating system is specified.

After assigning materials properties, boundary conditions are set. These include assignments of heat transfer coefficient values (also kept in a reference file), the ambient temperature, and the actual size of the cubes making up the model casting. In the first stage of the simulation, the steady-state temperature distribution in the die is predicted, and the freezing simulation program is run. The status of the progress of solidification within the current simulation step is shown, using a graphic bar on the screen. Calculations proceed until solidification is complete.

As with the rapid thermal simulator, results from this program can be displayed in several ways. Die surface temperatures can be mapped onto the casting shape and slices taken through the casting or die to view internal temperature distributions. In contrast with rapid simulation, actual temperatures are shown. An example of the results of these analyses is shown in Fig. 1

for a gear case casting. The color-coded temperature scale on the right assigns a different color to each range of temperature. A "slice" through the same casting is shown in Fig. 2. Variations of temperature with wall thickness and in proximity to the cores can be seen.

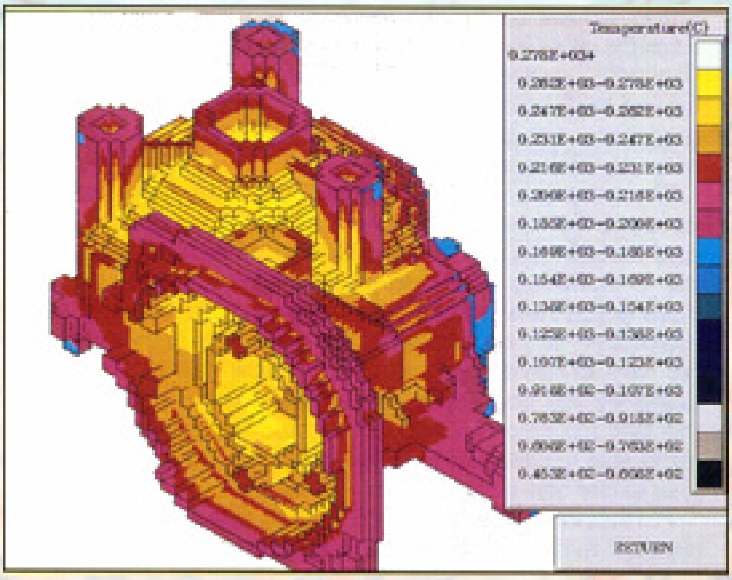

Fig. 1 Map of surface temperatures for a gear case casting produced with the DIANA program.

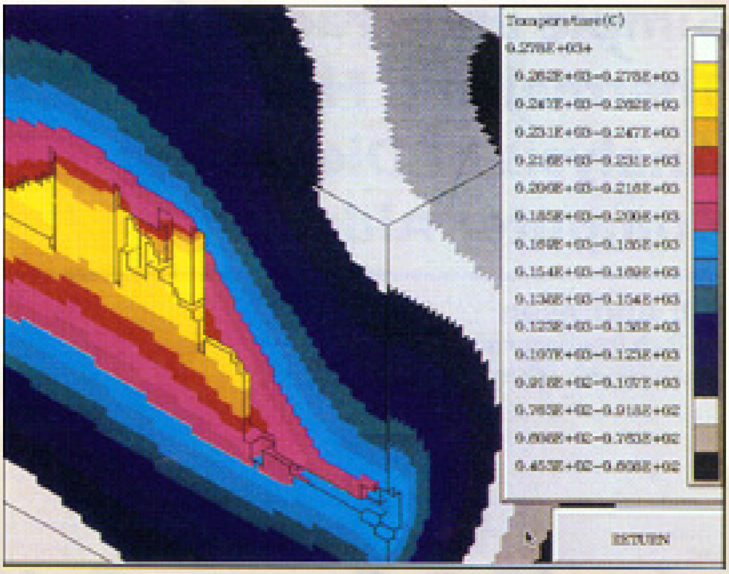

Fig. 2 A "slice" through the gear case casting shows the variations in temperature with wall thickness and proximity to cores.

With respect to solidification of the casting, 2D or 3D color-coded contour maps of the following can be presented on the screen: temperatures at selected times during freezing, freezing times at any location in the casting, and the Niyama coefficient distribution.
and it requires 32MB of memory. As mentioned, however, actual freezing times and temperatures are obtained for both the casting and the die.

Modeling of Shape-Dependent Shrinkage

As part of a current ILZRO research project, it is anticipated that the DIANA program soon will link the finite-difference thermal model to a finite element-based model to determine shrinkage for any part of the casting. Knowing the amount of free contraction that normally occurs, the casting shape and mechanical properties of the die, and solidifying casting, a stress analysis of the casting will be determined as the temperature falls. This will take into account free and constrained shape change while in the die, and free contraction after ejection. These stresses result in localized casting deformation that produce final casting shapes different from those predicted with the normal shrinkage rule.

First, the program's materials properties files can be checked to determine if any changes are necessary, the identity of the different materials having already been made in the thermal program. The model will then run, carrying out a stepwise simulation that calculates development of the state of stress resulting from cooling of the casting. The resulting deformations will be shown using color codes similar to those for the thermal freezing sequence results.

It also is anticipated that point-to-point dimension changes can be determined by specifying two locations of interest on the casting. The program will calculate the amount of shrinkage or expansion that occurs between them. These features should be of particular help in size and critical dimensions for die layout

Summary

Thermal analysis of dies and castings has been simplified to the point where an operator with little training can produce meaningful results on a personal computer with as little as 8 MB of memory. Rapid simulation requires only input of the casting shape, while the finite difference model, needing more memory, requires standard materials properties information. The costs of rapid simulation hardware and software should be compared with the costs of die rework and machine downtime that can result from inadequate thermal analysis. It is expected that the programs could pay for themselves over the course of a few die designs.