Use of Computer Simulation Technology in Engineering Education

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Abstract: The function of the engineering profession is to manipulate materials, energy, and information, in that way creating benefit for humankind. To perform this effectively, engineers must have knowledge of nature that goes beyond plain theory that is traditionally gained in educational laboratories. In recent years, however, the environment of these laboratories has changed. This paper describes the use of simulation technology in engineering education. In particular, the paper considers materials and metallurgical engineering field which involves many high temperature materials processing such as castings and solidification. In this study, an example of use of simulation technique to demonstrate the effects of casting geometry on solidification times of three different geometries in sand casting process been presented.

Introduction

The overall goal of engineering education is to prepare students to practice engineering and, in particular, to deal with the forces and materials of nature. Thus, from the earliest days of engineering education, instructional laboratories have been an essential part of undergraduate and, in some cases, graduate programs. Indeed, prior to the emphasis on engineering science, it could be said that most engineering instruction took place in the laboratory. As an example, in surveys of the articles published in the Journal of Engineering Education from 1993 to 1997, it was found that only 6.5 percent of the papers used laboratory as a keyword. From 1998 to 2002, the fraction was even lower at 5.2 percent (Wankat 2004).

Laboratory instruction has been complicated by the introduction of two phenomena in the past two decades: the digital computer and systems of distance learning, particularly over the Internet. The digital computer has opened new possibilities in the laboratory, including simulation, automated data acquisition, remote control of instruments, and rapid data analysis and presentation. Today, simulation software programs are available that accurately emulate many technical and physical processes. These software programs play an important role in engineering education (Quinn 1993).

Simulation is an important feature in engineering systems or any system that involves many processes. For example in electrical engineering, delay lines may be used to simulate propagation delay and phase shift caused by an actual transmission line (Kadlowec et al. 2002). Most engineering simulations entail mathematical modeling and computer assisted investigation. There are many cases, however, where mathematical modeling is not reliable. Simulation of such phenomena as fluid dynamics problems and materials processing often requires both mathematical and physical simulations (Kadlowec et al. 2002).

In education, simulation has been used to provide illustrations of phenomena that are not easily visualized, such as electromagnetic fields, laminar flow in pipes, heat transfer through materials, and electron flow in semiconductors or solidification of liquid metal in a mold (Kadlowec et al. 2002). Since simulators essentially execute mathematical equations and since we are able to develop reasonably accurate mathematical models of the physical phenomena we study in engineering laboratories, it is natural that simulators have been used as an adjunct to or even as a substitute for actual laboratory experiments. Simulations can be used as a pre-lab experience to give students some idea of what they will encounter in an actual experiment (Hodge et al. 2001). This can improve laboratory safety by familiarizing students with the equipment before actually using it. It also can result in significant financial savings by reducing the time a student or team needs on real—and expensive—laboratory equipment, thereby reducing the number of laboratory stations required. Simulations are useful for experimental studies of systems that are too large, too expensive, or too dangerous for physical measurement by undergraduate students (Baher 1999, Lee et al. 2001, Svajger and Valencic 2003).

In this study, an example of use of simulation technique to demonstrate the effects of casting geometry on solidification times of three different geometries in sand casting process been presented.

The Study

The objective of this study is to demonstrate how a simulation technique can be used instead of a real casting laboratory (or a foundry) for technology students in engineering education. The objective is to deliver to the students the effects casting geometries on the cooling and solidification time of liquid steel which allow solidifying in sand molds.

The Theoretical Aspect of the Study The theoretical aspects of this study were taken from an engineering textbook (Kalpakjian 1995) which deals with determining the solidification time of sand castings. During the early stage of solidification, a thin solidified skin begins to form at the cool mold walls and, as time passes, the skin thickens. With flat mold walls, this thickness is proportional to the square root of time. Thus doubling the time will make the skin √2=1.41 times, or 41 times thicker. The solidification time is a function of the volume (V) of a casting and its surface area (A), which is defined by Chvorinov's rule as;

$$\text{Solidification time} = C\left(\frac{\text{Volume}}{\text{SurfaceArea}}\right)^2 \qquad \text{Eqn [1]}$$

where C is a constant that reflects mold material, material properties (including latent heat) and temperature. Thus a large sphere solidify and cools to ambient temperature at much slower rate than does a smaller sphere. The reason is that the volume of a sphere is proportional to the cube of its diameter. Similarly, we can show that the molten metal in a cube-shaped mold will solidify faster than in a spherical mold of the same volume.

Example: Three pieces being cast have the same volume (1dm^3) but different shapes. One is a sphere, one a cube, and the other a cylinder with a height equal to its diameter. We can determine which piece will solidify the fastest and which one the slowest.

Solution: The volume is unity, so we have from Eqn 1;

$$\text{Solidificatio time} \propto \frac{1}{(\text{SurfaceAera})}$$

The respective surface areas are;

Sphere: $V=\left(\frac{4}{3}\right)\pi r^3$, $r=\left(\frac{3}{4\pi}\right)^{\frac{1}{3}}$, and $A=4\pi r^2=4\pi\left(\frac{3}{4\pi}\right)^{\frac{2}{3}}=4.84$

Cube: $V=a^3$, $a = 1$, and $A = 6a^2 = 6$

Cylinder: $V=\pi r^2 h = 2\pi r^3$, $r=\left(\frac{1}{2\pi}\right)^{\frac{1}{3}}$ and $A=2\pi r^2+2\pi r h = 6\pi r^2 = 6\pi\left(\frac{1}{2\pi}\right)^{\frac{2}{3}}=5.54$

Thus the respective solidification times t are;
Tsphere=0.043C, tcube=0.028C and tcylinder = 0.033 C. Hence the cube-shaped casting will solidify the fastest and the sphere-shaped casting will solidify slowest.

***Simulation*:** The above simple example of the effect of casting geometry on the solidification time of three different shapes was computer simulated as follows. The given casting geometries were drawn as 3D solid geometries using a CAD program. Each geometry was dimensioned to poses the required volume of 1 dm^3 liquid metal. The solid geometries were then imported into a 3D casting simulation software. The simulation software used in this study was able to create all the physical environment of a casting laboratuary or a foundry required to solidify liquid alloy in sand mold of three different shapes. A steel alloy (ST1020) was chosen as the casting alloy. Finally to solve required finite difference heat transfer equations the casting geometries were meshed with a 40 mm thick sand mold for each into 1000 000 cubic element. The meshed casting geometries were cut into two pieces from their common symmetrical planes to reduce the computation time as shown in Figure 1.

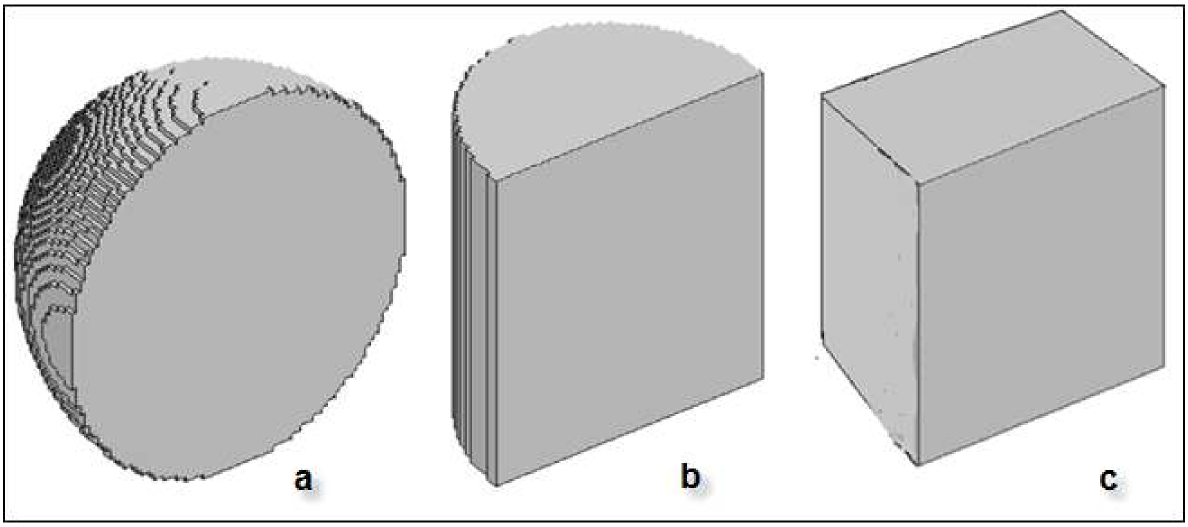

Figure 1: Isometric view of the meshed casting geometries used as models in simulation (as cut into half from symmetrical planes) a-sphere, b-cylinder and c-cube.

Findings

Simulations were performed in computer environment. For the sake of simplicity and to model exactly the same phenomena given in above example no running and feeding system was used in the casting model. Figure 2 shows a scene of cooling and progress of solidification for each casting. As seen from Figure 1 advance of solidification is fastest in cube-shaped casting and slowest in the sphere-shaped casting. This is in agreement with the above given results from solution of the example. That is, the engineering students attending this class will virtually see the solidification progress according to the theoretical rule and calculation without any real experimental work in casting laboratory.

After the simulation have been completed post simulation evaluations were performed. Solidification time of each casting is plotted to its quarter section of and shown in Figure 3. As seen from the figure the solidification has lasted 14.66 minutes in sphere, which is the longest time as calculated in above example. This is followed by cylinder and cube in exactly the same sequence as calculation. The smallest volume/surface area value was calculated for the cube-shaped casting leading to a smallest solidification time. Results from the simulation have also confirmed that the solidification has completed in 12.04 minutes in cube-shaped casting. It is also in agreement with the results from mathematical calculation. This example illustrate that the casting simulation technology can be useful to illustrate number of things which is difficult to or impossible when done in a real laboratory environment. Thus, in such areas as castings where molten metals and high temperature are often involved to experiment which might be dangerous, difficult and expensive to implement, laboratory can be substituted by simulation.

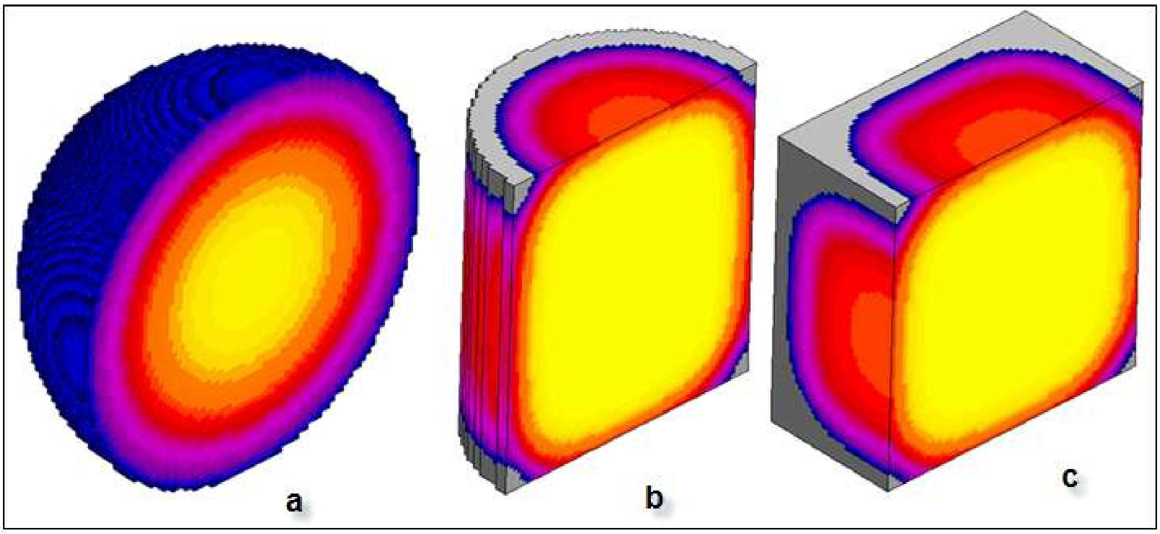

Figure 2: Cross-sectional view of progress of solidification in the cast parts a-sphere, b-cylinder and c-cube.

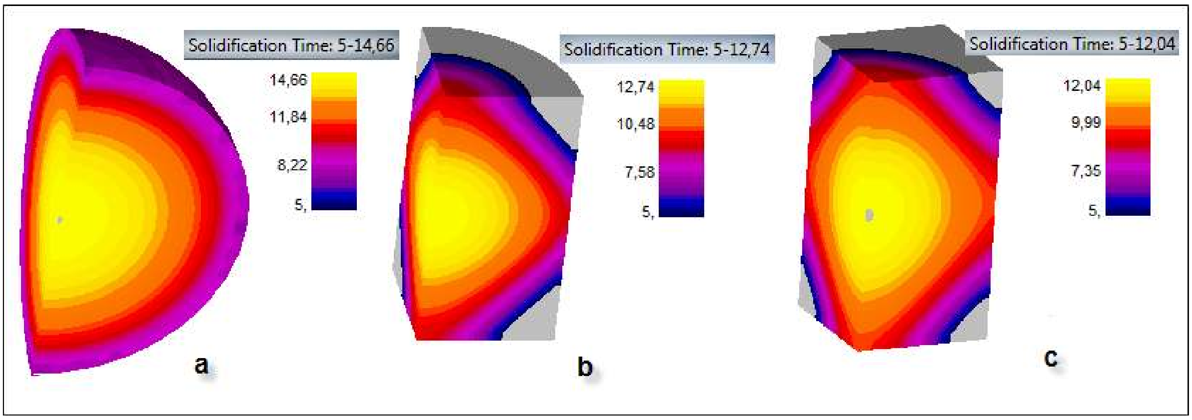

Figure 3: Plot of solidification times of the castings (qurter sections) a-sphere, b-cylinder and c-cube.

Conclusions

In this study, an example of use of simulation technique to demonstrate the effects of casting geometry on solidification times of three different geometries in sand casting process been presented.

Theoretical background and an example were given to calculate the solidification times of three different geometries as sphere, cube and a cylinder. Result from calculation showed that cube-shaped casting will solidify the fastest and the sphere-shaped the slowest.

Computer simulation of the solidification process with 3D CAD data of the geometries was also performed. Results from simulation were in excellent agreement with the result from calculations. This confirmed that casting simulation technology might substitute the casting laboratory in engineering education. This can be even more useful for such experiments where high temperature and expensive experimental set-up involves.

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