Paper ID #44781

Promoting Distance Learning in Metal Casting by Implementing Four Simulation Activities

Dr. Sam Ramrattan, Western Michigan University
Dr. Matthew Cavalli P.E., Western Michigan University

Promoting Distance Learning in Metal Casting by Implementing Four Simulation Activities

Sam Ramrattan & Matthew Cavalli
College of Engineering and Applied Sciences
Western Michigan University
Kalamazoo, MI 49008
Email: sam.ramrattan@wmich.edu & matthew.cavalli@wmich.edu

Abstract

The metal casting industry has less than thirty certified Foundry Educational Foundation (FEF) university/colleges in North America. For this reason, it is important to support and maintain quality educational programs. For the past thirty-five years, metal casting simulation tools have been affiliated with academia primarily in research and development. At the same time metal casting industry has adopted a digital approach to manufacturing where simulations play a major role. Educational institutes need to involve solidification and simulation technologies at the undergraduate level. Can solidification simulations be an effective tool to support student understanding of metal casting concepts in an introductory engineering course via distance learning? The authors investigated scaling up the use of a sequence of modules containing real-world simulation problems (hot-spot detection on castings, surface area-to-volume issues on castings, fluidity of various casting alloys, design optimization and yield calculations).

The implementation of flow and solidification simulations activities were explored in an introduction to Metal Casting course when the COVID-19 pandemic prohibited the conventional, face-to-face, and hands-on learning activities of the engineering course. Participants were eighteen sophomore/junior level engineering students at Western Michigan University during the Summer Semester 2020.

Casting flow and solidification predictive analysis were verified from actual casting trials where gating designs were experimentally evaluated preceding the course. The effectiveness studies were reported after comparing the evaluations of course assignment and examination scores prior and post the solidification simulation activities. At the end of the course evaluation, feedback from students was solicited regarding the distance learning solidification simulation experiences.

The simulation activities were described, and output analysis was provided. The experience conveyed insights into the role of simulation as an efficient and effective teaching tool in distance education. Results supported an adoption and implementation of the simulation software tool when teaching introduction to Metal Casting on any platform.

Keywords: distance learning, metal casting curriculum, solidification simulation; casting simulation analysis

Introduction

An introduction to Metal Casting course has been taught the same way for many decades. The prerequisite of this course requires an understanding of material science - metallurgy, fluids, and thermodynamics.[1] Ultimately a laboratory portion of the course was used to demonstrate the aspects of molding, melting, and filling; not forgetting industrial safety. In some cases, casting simulation software is presented or demonstrated but the technology is not central to the pedagogy in introduction to Metal Casting. The casting simulation technology is often reserved for more advanced courses involving solidification, risering and gating design.[2] Metal casting professionals have always encouraged a hands-on portion to an introductory Metal Casting course as being important. The authors of this paper support this idea and encourage a metal casting curriculum offering both theory and practice where conceivable for a proper understanding of the subject.

In 2020, the COVID-19 outbreak presented society with unprecedented challenges and operational disruptions. Moreover, industry and academia have been thrown into deep unknowns and faced new challenges to compete going forward. The foundry industry must shift gears to help address shortages regarding a trained/educated workforce and improving metal casting education is an answer.

The pandemic has changed our world where smart and resilient strategies are needed in education. Social distancing norms required certain university courses to be moved onto distance learning platforms, where faculty were required to adapt quickly to new technology, new teaching methods, and techniques. Engineering courses required modification where instructors and professors had to find innovative ways to blend theory and practice for technical subjects. The authors aimed to develop such an introductory Metal Casting course (EDMM 3520) at Western Michigan University (WMU). Furthermore, this 3-credit course (2 hours lecture, 3 hours laboratory per week) is usually offered over a sixteen-week semester schedule was being conducted during an eight-week 2020 summer session.[1]

This paper discusses how a simulation software can be made accommodating and beneficial in a distance learning environment to students equipped with a basic laptop computer. Additionally, the paper identifies modules used in conjunction with simulation activities to incorporate what was being taught in the conventional Metal Casting course. The outcome potentially can be used as a virtual introductory foundry training program. Flow and solidification simulation software provide a safe virtual setting to experience an animation of the metal casting process.[2,3] The software allows users direct exchange of input and output data. CAD data can be automatically acquired, and the geometry can be modified. Additionally, process data can be incorporated into models. The simulation software employed in this study utilizes contemporary computer and graphic technologies; similar and commensurate to that being used in the metal casting industry today.[3]

The philosophy of Industry 4.0/Foundry 4.0 is becoming more a reality. Thus, future engineers must be prepared in digital communication and smart data sharing technology. The conventional methods of teaching metal casting can result in repetition, confusion, delay, and eventually in some misunderstanding. Digital exchange using computer aided engineering tools such as casting simulations are being utilized to bridge the agility gap and provide predictive analytics for process control. The adage “a picture paints a thousand words” is true with simulation technology.

Impact of Casting Simulation

Casting solidification simulation software emerged in academia in the 1980’s. Approximately ten simulation tools are currently being used in the United States to support the metal casting technology. Solidification simulation tools are becoming more common in the metal casting industry. These tools enable learners to analytically understand complex systems; for example, working with the mathematics without the need of mastering formal equations. Still, simulation technology is not used to its greatest potential because of computational time and software cost. New casting simulation software can reduce simulation cost and turn-around time by orders of magnitude and make the use of simulation in daily practice a feasible reality. In addition, mold, melt and fill departments can all provide input and be involved in timely access to output information, including the graphical results of simulation analysis. The improvements in casting simulation technology over the decades have resulted in both higher quality simulations and castings.[3]

Implementation of a Suitable Software

A certain casting simulation software was selected for testing in the introduction to Metal Casting course. The main rationale for using this software system was that students can acquire flow and solidification analysis procedures in few clicks of the mouse.[3] This five-step approach provides a framework for sharing of information among different domains:

1. Import Model - Import CAD file or use geometry library to build model.
2. Select Part - Select basic casting alloys available and define gates.
3. Import/Create Components – Designate or create components like core, mold, riser etc.
4. Setup the Process - Setup process parameters for respective casting process
5. Run - Simulation and Analysis

This simulation system allows multiple jobs to be ran simultaneously and this is beneficial to students evaluating different processing parameters and/or boundary conditions. The computer platforms requirements do not require more than a standard laptop computer that our students already own. The bottom line is that it provides very comparable results to the much more expensive software systems in less time. Other simulation software systems require more than twenty-five steps/clicks in order to run the simulation. Moreover, due to a multiple step approach those casting simulation systems require intensive training to arrive at analysis.

Purpose

Casting simulation provides an integrating framework for associated CAD models, process changes, and out-of-the-box ideas to be evaluated, verified, and validated.[2,3] The simulation output often reveals opportunities to improve the process, hence the speed to reach findings is a value. With increasing computational power, casting simulation provides an opportunity for engineers to develop a new way of thinking and modeling. With digital big data sharing, faster computation and near real time analysis, simulation technology may become an "expert" system. Providing predictive analytics may one day supplant laboratory testing, defect diagnosis and recognition.

The aim of this paper is not to provide a review of the rapidly expanding technology that is casting simulation. Instead, this paper focuses on the use of simulation for aiding an introduction to metal casting course via distance learning. The purpose of this paper is to identify an approach utilizing simulations activities to teach a Metal Casting course via distance learning.

Objectives

1. To design distance learning using a simulation tool to introduce practical casting activities for an engineering course.
2. To compare metal casting students' outcome pre and post the use of the simulation tool.

Methodology

The goal was to develop and test a sequence of simulation activities designed to support student distance learning outcomes in an introduction to Metal Casting course.[1] The revised curriculum represented a variant of the activities used in a conventional Metal Casting course (EDMM 3520). Casting activities that were demonstrated in a working metal casting laboratory were converted to CAD models and used in casting simulation activities. A sequence of simulation projects was administered in activities over the course of the semester. The chronology of the simulation projects was designed to build on metal casting technology involvement with the complexity in logical systematic and sequential method.

Students were presented each simulation activity for a period of two weeks and studied the associated reading, videos, and lecture materials necessary to complete a technical report at the end of each activity. The aim was not to supplant the practical and hands-on aspects of a conventional course but to develop a teaching approach when the conventional teaching approach cannot be implemented or is disallowed. Students were evaluated from technical reports related to simulation projects, and electronic examinations were administered at the end of each activity.[1]

Four different activities were designed in such a way that it can cover the knowledge and understanding of metal casting field for engineering students.[2,4] All lab experiments and casting trials were performed in the WMU laboratory foundry in controlled laboratory conditions: the ambient temperature at 70 ± 2˚F (20 ± 1˚C) and relative humidity at 50±2%.

Activity 1: Determine Shrinkage in a Casting

Simulation solidification technology will be used for the lab to determine shrinkage related issues in casting. Students will be comparing two different simulation results under certain parameters.

Overview:
The purpose of this lab is to introduce the gravity green sand-casting process and study the flow and solidification using a simulation tool being used in industry. Instructor provided access to the simulation software program and training within an electronic classroom. The CAD model is shown below, and students must identify possible shrinkage porosity locations for given processing parameters.

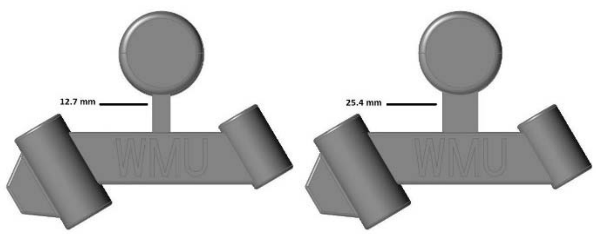

Figure 1. CAD image of Shrinkage model

Aim of the Activity:
1. To simulate and analyze a gravity aluminum green sand-casting process.
2. To determine shrinkage in a casting.

Simulation Software
Activity 1 consists of introduction to metal casting phenomenon. The major role of this lab was a demo of casting simulation technology. As mentioned earlier, casting simulation tool was introduced to the university engineering students.

The instructor provided CAD to the students to perform simulation on two different models and learn to operate simulation software. Students completed simulation on two brackets with different gate sizes. As a part of the assignment, students compared results between both simulation results. Below is the table which shows parameters provided by instructor for the task.

Table 1. Simulation parameters for Aluminum 356 alloy

Simulation Parameters (Image represents same time step)		
Temperature	720°C	720°C
Sprue Head Height	200 mm	200 mm
Gate Size	12.7 mm	25.4 mm
Core Sand Material	Silica	Silica

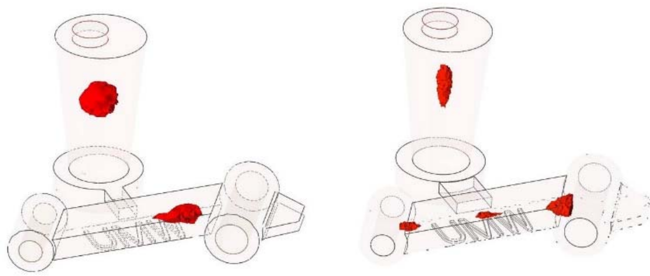

Figure 2. Simulation result of shrinkage porosity in 12.7 mm and 25.4 mm gate model

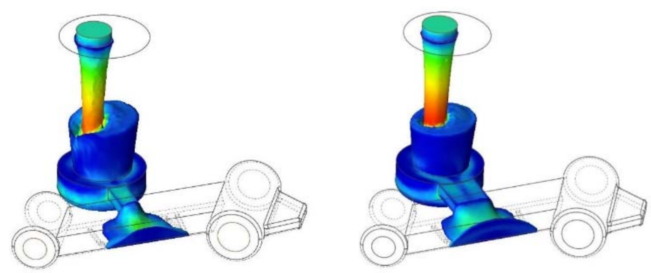

Figure 3. Simulation result of filling variance in 12.7 mm and 25.4 mm gate model

<u>Learning Outcomes:</u>
Activity 1 was oriented more towards basic learning methods and terminology. Students were introduced to casting simulation via demo session by an industrial expert. Additional outcomes are given below where students:

1. Understood technical terms for tools and equipment for manually producing a mold.
2. Reviewed gravity casting methods and types of casting processes.
3. Were introduced to technical components like core, refractory coating, chaplets, matchplate, etc.
4. Identified the importance and use of non-ferrous alloys in casting realm.
5. Understood the volumetric shrinkage behavior and compared for both the gating designs.
6. Analyzed solidification behavior from simulation results.

Table 2. Material properties of Aluminum 356 alloy

Material	C	Mn	Zn	Si	Fe	Pb	Ti	Cu	Sn	Mg	Al
Aluminum	<0.005	<0.10	<0.10	2.23	<0.20	<0.001	<0.20	0.213	<0.001	0.325	91.23
Al + 5% Si by weight	<0.005	<0.10	<0.10	7.22	<0.20	<0.001	<0.20	0.201	<0.001	0.319	88.26

<u>Activity 2: Study Hot Spots of the Castings and Effects of Surface Area-to-Volume</u>

Students will be learning the effects of surface area to volume in casting and understand the solidification behavior from simulation results to identify the hot-spot.

<u>Overview:</u>
Hot spots are regions in the casting that cools slower than the surrounding material.[4] A resulting defect is excessive contraction in that region termed shrinkage porosity. Any junction design in a casting generally shows a hot spot which plays significant role in solidification behavior.

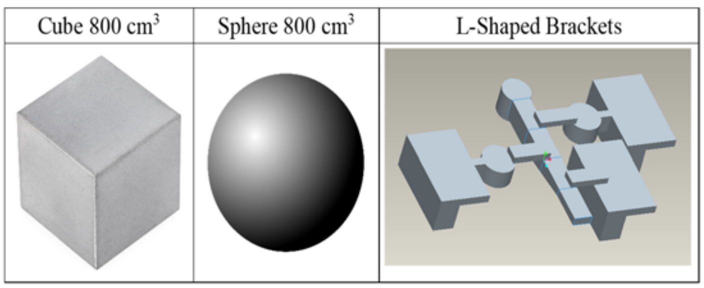

Figure 4. CAD image of Solidification model

<u>Aim of the Activity:</u>
1. To determine the effects of surface-area to volume
2. To identify "hot spots" on castings
3. To determine properties in casting alloys.
4. To identify the microstructure of in cast alloys.

<u>Simulation Software</u>
Activity 2 consists of introduction to metal casting components like core, sprue, filling system and types of casting processes such as gravity casting, high, and low pressure die casting. In this activity, an instructor provided four different geometries for the students to perform various casting simulation based on given parameters.

Students completed simulation on given geometries to observe difference in solidification behavior and hot-spot regions. Material, temperature and other setup parameters for simulation are given in table below.

Table 3. Simulation parameters for steel and cast iron

Part	Material	Temperature (°C)	Dimension	
Cube	AISI 1045 Steel	1700	all sides – 92.84 mm	Volume ~8x10^5 mm^3
Sphere	AISI 1045 Steel	1700	Dia. - 25 mm	Volume ~8x10^5 mm^3
L-shaped bracket	Gray Cast Iron 60	1430	CSA of the gate – 12.7 mm * 5 mm	

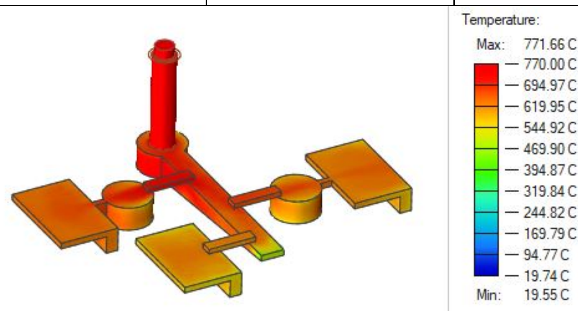

Figure 5. Filling temperature of L shaped bracket

<u>Learning Outcomes:</u>
Activity 2 was more specifically designed for students to understand surface area to volume and sand to metal ratio terminology. Students were given further detailed knowledge on gravity and die casting. Additional outcomes are given below where students:

1. Understood other technical terms for tools and equipment for die casting techniques.
2. Learnt die casting methods and types of die-casting processes.
3. Were introduced to technical components like chill, filling system, cooling channel, overflows etc.
4. Identified the importance and comparison of ferrous and non-ferrous alloys in casting realm.
5. Understood the hot-spot locations in different casting simulation results. Later compared with previously casted parts.
6. Completed data gathering the table. Here students were given empty table and they were supposed to be filling the values as given below.

Table 4. Value inputs by students on ferrous and non-ferrous materials

MATERIAL	**C**	**Mn**	**P**	**Si**	**Cr**	**S**	**Al**	**Pb**
Unalloyed	3.47	0.69	0.085	2.25	0.126	0.116	0.00016	<0.001
Alloyed	3.33	0.41	0.075	2.22	0.102	0.111	0.00008	<0.001
	Ti	**Mo**	**Cu**	**Sn**	**Ni**	**Sb**	**Mg**	**Fe**
Unalloyed	0.108	0.017	0.12	<0.001	0.06	<0.001	<0.001	93.06
Alloyed	0.076	0.016	3.68	<0.001	0.05	<0.001	<0.001	90.46

Activity 3: Flowability and Feeding Test for Cast Alloys

Students will analyse the fluidity data of run distance versus alloy superheat to determine the casting/mold thermal boundary conditions. Working with the same alloy and the information gained about flowability; students must design a rigging/gating system and identify the processing parameters using simulation for a casting that is being taken into production.

Overview:
There is theory concerning the run distance of alloys.[4] For a Newtonian mold-casting interface condition:

$$L = v * \left[\frac{\rho * \Delta H_{eff}}{h * (T_m - T_o)}\right] * \left(\frac{V}{A}\right) \quad \text{eq. 1}$$

Where:
- L = run distance
- v = gate velocity
- ρ = alloy solid density near the melting temperature
- ΔH_{eff} = effective heat of fusion = $\lambda \Delta H_f + c_p \Delta T$
- λ = fraction solid to suppress flow
- ΔH_f = heat of fusion of alloy
- c_p = isobaric specific heat of liquid alloy
- ΔT = alloy superheat = T_{pour} - $T_{Liquidus}$
- T_m = pouring or liquidus temperature of the alloy
- T_o = initial temperature of the mold
- V = volume
- A = surface area

A more general solution for thickness solidified versus time, or equivalently, the time to freeze as a function of casting effective thickness, is given by Geiger and Poirier.[4]

The purpose of this lab activity was to study the fluidity and feeding of aluminum casting alloys. The fluidity spiral casting method will be used as shown in the pictures below.

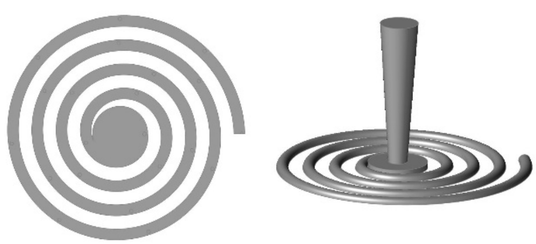

Figure 6. CAD image of Fluidity model

The activity asks students to simulate three molds using the spiral fluidity pattern for the same casting process and then fill the molds with an alloy at three different superheat temperatures (high, medium, and low). Students note the superheat of the alloy at the start of pouring, the time to pour, and the distance the molten alloy fills the spiral.

Aim of the Activity:

1. To demonstrate how pouring temperature affects flowability and feeding.
2. To demonstrate how the alloy content affects flowability and feeding.
3. To demonstrate how pouring temperature affects defects.

Simulation Software

Activity 3 consists of introduction to metal casting components like core, sprue, filling system and types of casting processes like gravity casting, high, and low pressure die casting. In this activity, an instructor provided different geometries for the students to perform various casting simulation based on given parameters.

Students completed simulations on given geometries to observe difference in solidification behavior and hot-spot areas. Material, temperature and other setup parameters for simulation are given in table below.

Table 5. Simulation parameters for fluidity test

Part	Material	Temperature (°C)	Head Height (in)	Mold Material
Spiral	Al 356	600	4	Silica or Zircon
		675		
		720		

Figure 7. Fluidity result of spiral at different temperature

Learning Objectives:

Activity 3 focused on temperature variance while filling narrow and longer travel path inside the cavity. Fundamentally, this activity was to understand fluidity and metal flow behavior against time by using gravity casting techniques. Additional outcomes are given below where students:

1) Understood other technical terms for tools and equipment for metal flowability related techniques.
2) Learnt die casting methods and types of die- casting processes.
3) Were introduced to technical components like sleeves, filters, alternative molding media etc.
4) Identified defects associated with fluid flow like thermal erosion, flash, cold shut etc.
5) Found the optimal temperature at which cavity could be filled to the fullest using simulation experiments.
6) Determined the maximum flow length an alloy can achieve at different processing temperatures.

Activity 4: Perform Investment Casting

Students performed casting simulation on investment casting process and compared the results with actual casting of the same geometry.

Overview:

Activity 4 is designed as a final project activity for the students. As an initial step, students were supposed to develop a coreless casting design that houses a solid sphere sitting on a hexagonal plate. The sphere is roofed by three congruent triangular plates each touching the sphere tangentially. Points from each of the triangles meet at the top and their bases are attached symmetrically about the sides of the hexagonal plate. The finished casting must have a maximum height of 9" with a maximum base diameter of 5". Students could select a different pouring alloy. However, the mass of the casting and gating cannot exceed 2 kg. The casting design must be presented with the gating system intact. (Note: Students were given the freedom to choose a casting design of their own; however, the casting design must receive the instructor's approval.)

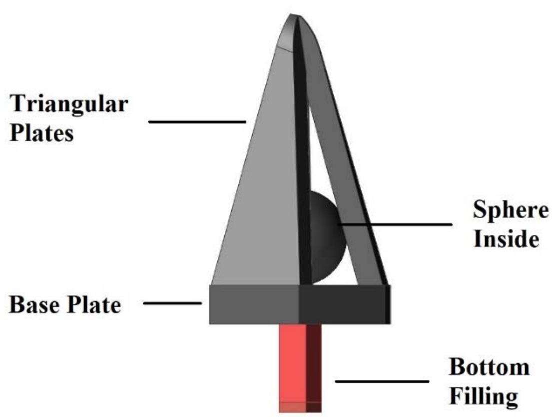

Figure 8. CAD design of investment casting model

Aim of the Activity:

1. To demonstrate proficiency in the investment casting process.
2. To demonstrate teamwork when completing a final project.
3. To optimize the design and achieve maximum yield.

Simulation Software
Activity 4 consists of deep learning to Investment casting processes. As mentioned earlier, students designed their own model in groups of either 3 or 4. After CAD completion, designs from each group were evaluated to check the fulfillment of minimum criteria and requirements.

After instructor's approval for CAD, students performed Investment casting simulation under certain parameters. Different results like filling temperature, porosity, shrinkage factor, and solidification behavior were analyzed for further consideration. For example, material, temperature and other setup parameters for simulation are given in table below.

Table 6. Simulation parameters for investment casting simulation

Part	Material	Temperature (°C)	Bottom Fill	Mold material
Investment Casting	Aluminium 319	708	2 in	Zircon

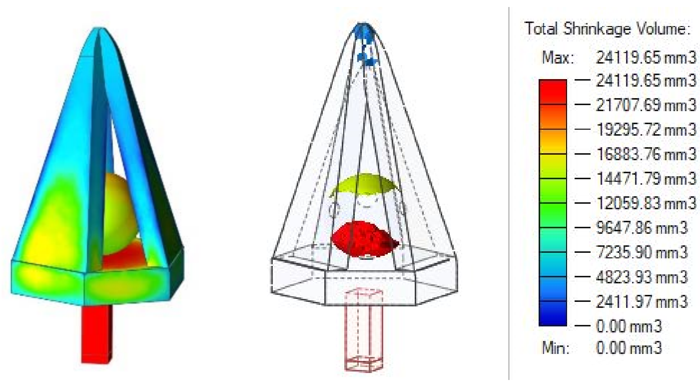

Figure 9. Simulation result of investment casting model.

Procedure
Activity 4 was redesigned in such a way to fit in the distance learning curriculum. Here students did not perform actual casting trials in WMU foundry as a final project. Instead, they created CAD for the model and ran simulation of Investment casting. Results of this casting simulation were later compared with existing as-cast parts and processing parameters. Below are the procedure steps for conventional investment casting activity from a previous semester.

Polystyrene foamed plastic can be cut with a knife, band saw, or hot wire into any shape and glued together (Elmer's rubber cement is satisfactory) to develop a pattern/gating system. Interesting effects can be achieved by inserting metal rods through plastic foam patterns that are to be poured with metal.

- The pattern/gating system can be coated by dripping with a permeable refractory coating formulated for expandable polystyrene, then dried to produce smoother "as cast" surfaces.
- A rigid flask must be used to withstand vibration and the weight of the sand. The flask must be vented to permit rapid escape of the gases formed by the vaporization of the pattern.
- Pour in 3 inches of sand into the flask. Set the Styrofoam pattern/gating system on the sand and riddle in more loose sand.

Proceedings of the 2024 ASEE North Central Section Conference

- Actuate vibrator and add more sand to ensure that sand is properly compacted around the pattern and fills in all openings and undercuts (remember no cores are needed with this process).
- A riser insulator is used to form a pouring basin with the top of Styrofoam sprue extended into the pouring basin and out of the sand about 1".
- After the pattern has been packed and the mold vibrated, the pouring procedures are administered. Pour rate is determined by the rate at which the pattern vaporizes. A constant head of metal must be maintained throughout the pour by keeping the pouring basin full.
- After solidification, the casting is ready for shake-out.
- Cleaning the foundry area was essential task for each group as a part of activity after casting trial.

<u>Considerations in the Lost Wax Casting Process</u>
Apart from lost foam, lost wax process in investment casting methodology was introduced from a teaching perspective. Process steps are mentioned below:

- Produce wax patterns by wax injection molding
- Develop investment tree
- Invest the mold using refractory materials (this step can be accomplished by repeatedly dipping in refractory slurry and stuccoing with sand to build up a ceramic shell).
- De-wax molds
- Pour metal
- Solidification of casting
- Shake out the casting and remove the coating

<u>Learning Objectives:</u>
For conventional teaching method, Activity 4 was supposed to be the final semester project where students design their model in groups, performed simulation, build the model using foam and later pour metal inside. In other words, final activity was also considered as a hands-on project for students. Some other outcomes are given below where students:

1) Understood other technical terms like yield percentage for metal flowability related techniques.
2) Learnt Investment casting terminology and difference in lost wax and lost foam casting methods.
3) Analyzed and optimized the design based on simulation prediction to avoid defects like porosity, cold shot, misrun.
4) Simulation analysis and Optimization were done in a single environment of simulation system without the use of additional CAD systems.
5) Learnt the methodology of Design for Manufacturability.
6) Gained in-depth knowledge of simulation tool and its importance, working on a project as a team and achieve 80% yield or above in final casting.

Results and Discussion

The new distance learning curriculum used nearly identical content with the conventional Metal Casting course (EDMM 3520). The distance learning curriculum incorporated a series of activities (4) each of which contained lecture slides, related reading, videos presentations, and casting simulation projects. The distance learning environment is very different from the conventional face-to-face classroom. Laboratory demonstrations and data gathering were replaced with simulations and questions related to output. The simulation tool was used to performed demonstrations and conduct experiments pertinent to the content of the activity being studied. All distance learning class sessions were recorded by students for review and for discussion.

Curriculum goals/objectives of activities were aligned with key learning outcomes. At the end of each activity the key learning outcomes were assessed from a technical report and examination. Key to the organization of these activities was the sequencing of the simulation projects and lecture-based materials. The conceptualized modes for casting simulation began with simple CAD and the number of process variables were restricted. Activity objectives and learning outcomes were enhanced in a systematic and sequential manner to address scientific reasoning and engage students with real world casting issues.

Effectiveness of Casting Simulations

With input from a software expert, a training manual and help menu were made available to students using. Students utilized casting simulations in every aspect of the course, with classroom demonstrations, for discussion, and for course assignments. After the demonstration, students were able to manipulate the simulations systematically in order to conduct experiments and produce output data.

Distance learning efficiency was observed with the use of casting simulation in Metal Casting course:

- The value of including the digital graph and CAD model together were explored in the distance learning course.
- Presenting real world casting activities through interactive computer simulations provided students with an active learning experience, allowing them to engage in ways that might otherwise be impractical or impossible. In the distance learning course, casting simulations presented in-mold visualizations of what might be considered hazardous hot metal processing details, otherwise not readily observable within the conventional course. Certain activities in the distance learning course considered CAD models from industry. The students enjoyed using an industrial tool to solve industrial problems.
- Simulations are most effective when used together with course work, rather than in lieu of, other separate learning experiences.

Students were given actual castings from each activity after obtaining simulation results to compare visually. Typical examples shown in Fig.10 and 11. Fig.10 represents three different fluidity lengths and Fig.11 was used to study yield. Images are given below showing the castings after shake-out and clean for observation.

Figure 10. Casting produced by aluminum 356 at different temperatures using gravity casting

Figure 11. Casting produced by gray iron lost foam (left) and aluminum investment

Table 7 summarizes learning outcomes for each activity and the accompanying pedagogical methods used in conventional and distance learning formats.

Table 7. Comparison of teaching methods between conventional and distance learning methods

Activity #	Learning Outcomes	Distance Learning	Conventional Methods
1	• Green Sand-Casting Terminology, • Technology – cores, core prints, chaplets, Non-ferrous alloys • Hot Spot and Shrinkage porosity defect • Introduction to the Simulation in 5 easy steps	• Online Lecture • Related Internet Reading Material • Online Video presentation • Casting Simulation • Simulation Training	• Classroom Lecture • Related Text Reading and Course Manual • Video presentation in classroom • Casting Simulation • Performed Lab Casting Trial
2	• Gravity and Die casting Terminology • Technology – Chills, Refractory coating, Ferrous and Non-ferrous alloys • Casting concepts- Surface-Area to Volume, Sand-to-Metal Ratio, Junction Designs • Solidification Simulation		

3	• Properties of Alloy, • Alloy Flowability, • Technology - filters, sleeves, chills, alternative molding media • Cold shut, Flash, Erosion, Thermal gradient at mold/metal interface and Thermal conductivity of sand • Filling Simulation		
4	• Investment Casting Terminology • Gating Design, • Yield (production & pattern), • Sand-to-Metal Ratio, analyze and Optimization • Design for Manufacturability		

Instructor Observations

- The casting simulation activities supported new forms of classroom interaction during distance learning. Digital data exchange encouraged student engagement with modeling and design aspects of the activities.
- The use of simulation software encouraged structured and logical thinking by the students where they were able to relate process parameters/variables with process issues and casting defects.
- Casting simulations output provide learners with visual representations of dynamic theoretical entities that are difficult to represent in the casting laboratory or gain from a casting textbook but are critical for understanding why matters of flow, fill, and solidification behave as observed. These simulations can also encourage active learning by giving students opportunities to manipulate models.
- To encourage academic honesty each student was provided with a unique set of casting parameters and/or boundary conditions. The simulation can be rerun, subjected to alternative scenarios and assumptions, presented through different graphing lenses or analyzed with CAE tools. Once the simulation activity had been enacted, a major vehicle enhancing learning was the exchange of data and discussion among the students.
- At times science can be poorly taught, and students lose interest, electing the loss of student interest. The casting simulation tool in the secluded distance learning environment provides companionship that fosters interest and improves interactive learning.

Student Course Ratings

WMU's online course rating system was used to gather students' responses for EDMM 3520 Metal Casting course. On average, 20 students were enrolled in the course each semester. Student responses were compared over the last four semesters to gauge students' interest, attitude and motivation for the course. Table 8 is used to summarize the course evaluation. Responses were evaluated from 0-5 score limit where 5 is the highest rank.

Table 8. Likert EDMM 3520 course rating responses (5 = + / 1 = -) over four semesters

QUESTIONS	F18	S19	F19	S20
What was your pre-course opinion of the course?	4.2	4	4.1	4.5
Overall, how would you rate this course?	4	4.5	4	5
How do you like the teaching methodology for this course?	4.5	4	3.8	5
Did you improve your technical knowledge?	4.5	4.5	4.5	5
How well did examination questions reflect content and emphasis of the course?	4	4	4	5

Limitations

Distance learning strategies were limited to one summer semester (8 weeks). Foreshortened teaching period had not been used with this course prior. However, after course completion, students indicated an interest in hands-on laboratory experiences that supplements simulation technology.

Conclusions and Recommendations

This paper focused on the technological aspects of a casting curriculum that substitutes in conventional and non-conventional academics. During a pandemic period and thereafter, engineering education was benefited by pedagogical enhancement using casting simulation.

There were several benefits of using the casting simulation activities within curriculum. These advantages were:

- Activities were designed for practical application in the metal casting industry (terminology, process technology, gating and risering, defect identification and control)
- Integration for processing, material science, fluid, and thermodynamics in metal casting
- Education and training programs to deal with uncertainties and disruptions
- Digitalization and data analytics for Foundry 4.0
- Activities were related to a variety of sand, die, and investment casting processes
- Innovative software tool that is easy and quick to adapt to educational needs.
- Ideas for workforce re-training, re-skilling, and re-deployment using metal casting simulation software.

Conclusions are stated in terms of participant (student) responsiveness and course differentiation. Participant (student) responsiveness: Student receptiveness and reactions to the casting simulation distance learning in Metal Casting course were gauged through WMU Online Course Evaluation System. There was no negative sentiment regarding the use of casting simulation in EDMM 3520 Metal Casting Summer 2020. Enrolled students gave a positive review of the course; however, several students indicated a preference for the face-to-face teacher-student interactions with hand-on laboratory activities.

This paper touches on an essential issue in metal casting education (science and philosophy). It identifies that metal casting students prefer a hands-on learning environment that is supplemented and complemented with casting simulation software. The cost of safety protocols, materials, supplies, space, and laboratory technicians necessary in running hands-on engineering labs is a concern to academic administrators. For these reasons certain universities and colleges have invested in virtual laboratories. American metal casting educational institutions such as the Foundry Educational Foundation (FEF), the North American Die Casting Association (NADCA), the Investment Casting Institute (ICI) all favor a laboratory-based metal casting curriculum where casting simulation tools are employed.

Course differentiation addresses the issue of how using casting simulation in the distance learning version differs from the conventional Metal Casting course in quality and effectiveness. A qualitative approach was used to assess the quality of delivery and effectiveness of learning outcomes from each activity. An examination was administered at the end of each activity and the results were used to compare both new and conventional curricula. Assessing the quality of delivery and comparing the distance learning approach with the conventional approach is the coauthor and FEF Key Professor with more than thirty years of experience in metal casting education.

Casting simulation allows students to analyze not just laboratory - based outcomes but also connect strongly to theory and practice in working foundries. The casting simulation helped to reinforce all learning outcomes in all activities of a Metal Casting course. The authors' stance is that the casting simulation in higher education stands for technology literacy, a new way for students to describe and view the metal casting process. Our world is constantly changing, Industry/Foundry 4.0 is a trend today and casting simulation is a pillar representing digital analytics, virtual reality, and engineering science to students of metal casting.

It is recommended that the casting simulation distance education course be adopted to complement a conventional and/or hand-on casting course. Additionally, the casting simulation distance education course can be modified for use in industrial training programs. The authors are willing to supply CAD models used in all activities discussed in this paper.

Acknowledgments

Authors thank Altair Engineering for research and software technology support.

References

1. EDMM 3520 Metal Casting on Western Michigan University eLearning, Summer 1 2020 wmich.edu/eLearning
2. Metal casting Principles & Techniques, 1st Edition, Dec. 2013 American Foundry Society, ISBN: 978-0-87433-399-2.
3. Altair Online Training Materials for Inspire Cast, https://2020.help.altair.com/2020.1.1/cast/en_us/topics/shared/get_started/training_support_c.htm
4. Transport Phenomena in Metallurgy, Addison-Wesley series, by David R. Poirier, G. Geiger, 1st Edition 2016, ISBN 978-3-319-48090-9.