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E-Foundry: Free Online Learning Resources in Casting Design and Simulation

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ABSTRACT

Advanced technologies such as automation, CAD and simulation that are being adapted in metal casting industry require technically qualified human resources. There is however, a severe shortage of competent teachers in this field. To overcome this gap, IIT Bombay has developed E-Foundry (http://efoundry.iitb.ac.in), comprising free online learning resources in casting design and simulation based on teaching and research work accumulated over the last 20 years. The heart of E-Foundry is a cloud-based Simulation Lab, which allows users to upload their CAD models and view solidification simulation results within minutes. This is supported by virtual classroom, library, tutorial, projects, and discussion hub. Several hundred teachers in different institutes have been trained to use these resources to support their own theory and lab courses. In the last one year, over 38,000 people from all over the world have visited the site, and over 4000 castings have been simulated online. These learning resources are benefitting a much larger number and geographic distribution of students, teachers and industry professionals, compared to conventional courses. This is expected to help revive interest in metal casting, leading to better human resources for not only working in industry, but also to engage in research and development.

Keywords: Metal Casting, Design, Simulation, Internet, Cloud Computing, Education, Training.

INTRODUCTION

Manufacturing sector in general and foundry industry in particular, face two challenges with respect to technical human resources. One is shortage of young engineers joining the workforce, in spite of prevailing levels of unemployment. The second is employability, caused by academic institutes unable to provide relevant industry-ready training. These problems are threatening the competitiveness and even survival of the foundries, especially small and medium units.

With nearly 10 million tons of casting production, Indian foundry industry is next only to China. There are about 4500 foundries, employing an estimated 500,000 persons directly and another 1.5 million indirectly[1]. Nearly one third (32%) of the foundry output goes to the automobile sector, followed by sanitary, pipes and fittings (16%); agriculture and earthmoving (10%); valves, pumps and compressors (9%); industrial machinery and machine tools (9%); power generation and electrical equipment (7%); and railways (5%). Most of the Indian foundries are located in clusters at Howrah, Batala-Jalandhar-Ludhiana; Delhi-Agra-Jaipur; Ahmedabad-Rajkot; Mumbai-Pune; Kolhapur-Belgaum; Bangalore-Coimbatore-Chennai; Hyderabad-Vijayawada; and Nagpur-Indore-Bhilai. More than 80% of these foundries are classified as small-scale units, 15% as medium-scale units, and less than 5% as large-scale units.

Notwithstanding the dip in the last one year, the Indian automobile sector is envisaged to grow four-fold from US$ 34 billion in 2006, to over US$ 140 billion by 2016, coupled with additional employment generation of about 25 million, according to the Automotive Mission Plan. This in turn requires a sustained infusion of fresh manpower in the foundry industry. The Foundry Vision 2020 projects the requirement as 20,000 workers (skilled and semi-skilled) and 2000 engineers, plus 100 competent teachers to impart the necessary training[2].

The Office of the Development Commissioner (MSME), Nirman Bhavan, New Delhi has exhorted foundries to shift from traditional low-value, low-technology products requiring large factory areas, to high-value special products for niche markets, which could be produced in compact units with environment-friendly technologies[3]. Computer simulation has been identified as a key desirable technology. An industry survey involving several hundred foundries clearly showed that foundries using simulation technology reported half the level of defective castings compared to those who did not use the technology[4]. Other benefits include shorter development time, improved yield, and customer satisfaction. Yet, the penetration of simulation technology is very poor (estimated to be less than 10%) in Indian foundries. The major bottleneck was reported as lack of technical manpower. A recent annual report of the Institute of Indian Foundrymen also reports that the acute dearth of skilled manpower has become the biggest hurdle confronting the foundry industry[5].

Very few Indian institutes provide specialized training in metal casting. The most prominent one is the National Institute of Foundry and Forge Technology at Ranchi. The recent Institute of Technology established under Nirma University at Ahmedabad offers an Advanced Diploma in Foundry Technology. A few tool-rooms such as Nettur Technical Training Foundation, Bangalore; Central Tool Room & Training Centre, Bhubaneshwar; and Central Institute of Tool Design, Hyderabad offer diploma-level courses related to foundry technology. Polytechnic institutes continue to be the major source for technical manpower for manufacturing industry, including foundries. At present, there are an estimated 1500 polytechnic institutes in India, but very few of them (for example, Government Polytechnic, Kolhapur) have dedicated programmes in foundry technology.

Another matter of concern is that most of the newer engineering colleges do not have metal casting facilities, and older colleges are dismantling the facilities due to lack of space, cost of maintenance and safety issues. While computer simulation allows observing the physical phenomena involved, the software programs are too expensive to be implemented in lab courses in academic institutes. Thus engineering students do not get any opportunity to develop an interest in metal casting.

In short, foundry industry is caught in a vicious cycle as far as technical manpower is concerned. There are very few teachers and institutes preparing students for employment in foundries. As a result, the metal casting industry is unable to adapt newer and more advanced technologies like automation and simulation. This in turn makes the industry even less attractive to the younger generation, as well as teachers and researchers. As a result, most foundries are forced to down-skill, impacting casting quality and competitiveness.

In this context, IIT Bombay took the lead to develop web-based learning resources in casting design and simulation that can be freely accessed by students, teachers, and industry professionals worldwide. This is based on teaching and research carried out at the institute over the last 20 years[6], redesigned for online access at http://efoundry.iitb.ac.in (Fig. 1). The heart of the system is a cloud-based simulation lab, which is described next, followed by other learning resources including lesson videos, library of animations, paper abstracts, and industrial case studies, as well as tutorial exercises, project ideas, and discussion hub. In the end, we describe teacher training programmes, student certification model, and overall impact assessment.

Fig. 1. E-Foundry home page

CLOUD-BASED SIMULATION LAB

Cloud-computing frees users from purchasing, installing and maintaining complex and expensive software programs that work only on dedicated stand-alone computers. The E-Foundry Sim Lab can be accessed by any one, at any time, from any computing device (PC, laptop, tablet, smartphone) connected to the Internet. The interface is shown in Fig. 2. The user only needs to upload the CAD model of the casting (in industry-standard .STL format), select the cast metal, mold material, and mesh size (coarse or fine). The casting model is uploaded to the E-Foundry server, which takes a few minutes depending on the file size and overall connection speed. The server checks the file, generates its 3D view, and sends the image to the user’s device for visual verification. After user confirmation, the simulation program on the server subdivides the casting model into a fine or coarse mesh, computes the solidification temperatures, post-processes the results to generate colour-coded images, and sends the images to the user’s device. The user can save the images for future reference. All this takes less than ten minutes per request.

The colour-coded results show the relative temperatures in different regions of the casting at the instant of solidification of the hottest region. Thus hot spots (prone to shrinkage porosity), cold spots (prone to cold shuts) and high gradient regions (prone to hot tears) can be potentially identified. Based on these results, foundry engineers can model the feeders, upload the combined model to the Sim Lab, and verify the feeder design (location, shape, and size). Product engineers can check and modify the part design (wall thickness, tapers, ribs, fillets) to ensure directional solidification and ease of feeding. Tooling engineers also find it useful to determine the most appropriate orientation of the casting in mold, to ensure it is easily feedable and fettlable.

The solidification simulation is based on Gradient Vector Method, which relies on computing the vector sum of thermal flux vectors around a given point, to find the direction of the largest thermal gradient at that point[7]. This method is found to be ideal for quick computation of casting solidification temperature and hot spots, without detailed thermo-physical properties and interfacial heat transfer coefficients required by other numerical methods. It however, assumes that the mold is already filled (before start of solidification), making it suitable for mainly gravity processes (sand and permanent mold) of thick-walled castings. The GVM has been extensively validated through experiments as well as comparison with FEM based casting simulation programs[8]. The speed, accuracy and ease-of-use of GVM make it eminently suitable for student lab exercises.

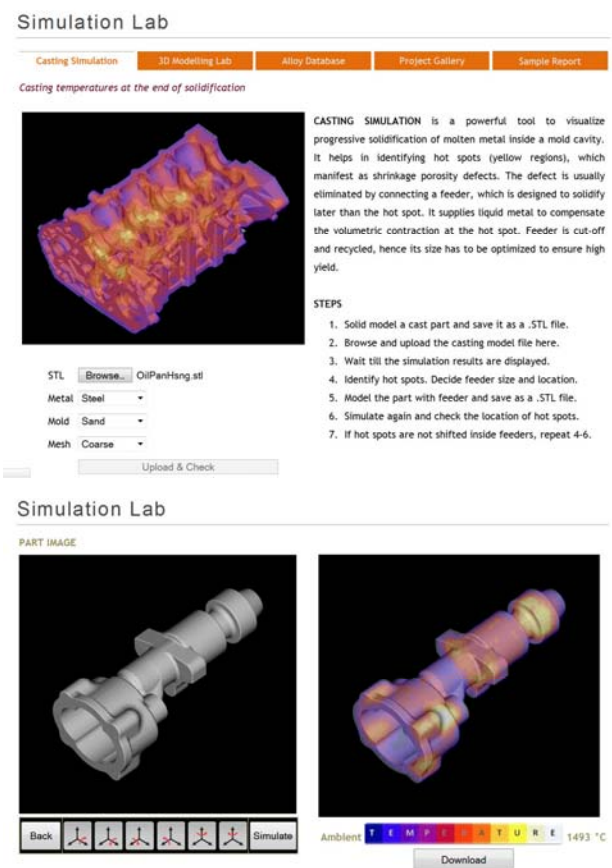

Fig. 2. Online Sim Lab: user inputs and results

OTHER LEARNING RESOURCES

Other learning resources at E-Foundry are prompted by the rapidly increasing popularity of ‘flipped classroom’ pedagogy. Students view lecture videos at ‘home’, and do their ‘home work’ in class rooms. This has been shown to be more effective, since the students can go through the lectures at their own comfort and pace; and teachers’ time is more effectively used for providing individual attention during class exercises. Accordingly, a range of learning resources has been created at E-Foundry, including virtual Classroom, Library, Tutorial, Projects, and Discussion Hub. These are briefly described here.

Classroom comprises 45 lesson videos, divided into five parts with learning goals ranging from basic theory to advanced applications. Each part includes 9 lessons. Each lesson includes a video, soft copy of slides, quiz, and rating feedback (Fig. 3). The lesson videos have a well-edited blend of the speaker, presentation slides, and audience interaction. The lessons are typically 10-20 minutes, ensuring good attention. The movie format and size have been optimized for easy downloading and viewing on typical Internet connections in India. The slides have been designed for readability even on smartphones.

Library consists of different sections, providing a range of useful and interesting resources for teachers, students, researchers and industry professionals (Fig. 4). Animation and video section includes major casting processes and lab experiments. Books and papers section includes abstracts of over 1000 carefully selected technical papers published worldwide. Simulation cases include over 30 examples of industrial casting simulations. Web links points to research institutes and professional bodies in different countries, along with their short descriptions. Defects museum will include images of different types of casting defects. A search facility has been added, along with a list of the most widely used keywords.

Tutorial includes 18 exercises in casting design starting from volumetric properties to core design, mold layout, feeder design, gating design, casting yield and tooling cost (Fig. 5). User can select one out of five casting shapes, and one out of five cast metals, giving 25 different combinations of answers. The numerical answers are automatically checked online, and immediate feedback is provided. This ensures that the later questions, whose answers depend on the previous ones, can also be attempted successfully. The scores are recorded in the individual database of the user, identified during login.

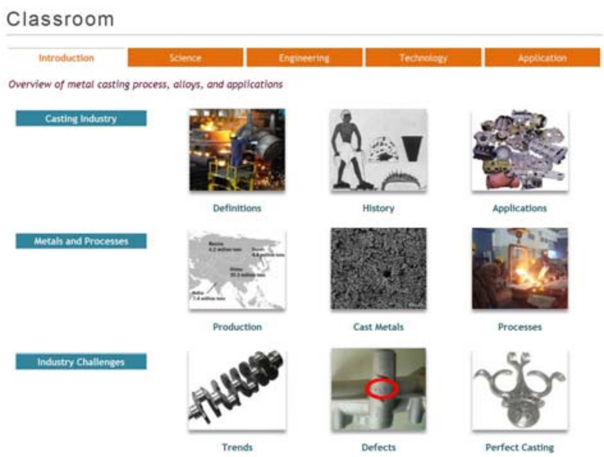

Fig. 3. Online classroom lessons

Fig. 4. Online library resources

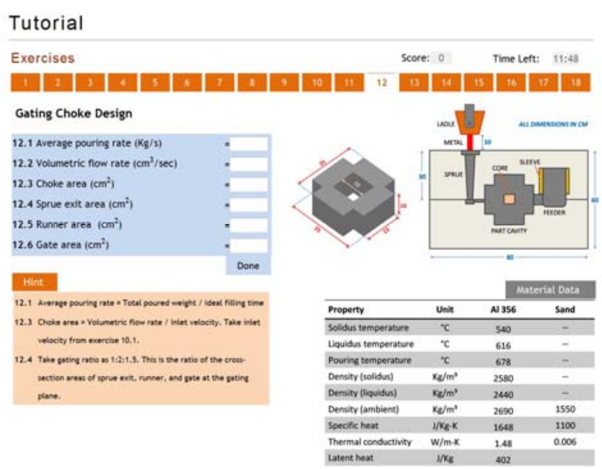

Fig. 5. Online tutorial exercises

Fig. 6. User dashboard with scores

Projects and Hub sections are meant for enhancing interaction between the members. The Projects page includes profiles of active casting researchers, and ideas for research projects under different categories, which are being continuously updated. The goal here is to encourage students to get in touch with the researchers and explore projects for their Bachelor's, Master's, or Doctoral degrees. The Hub is meant for posting technical questions and answers. The discussion threads can be viewed by others for information.

All above learning resources can be accessed from the home page of E-Foundry. Some of the resources, particularly the Sim Lab, Tutorial, and book downloads, require the user to log in first. The user registration is simple and free. Registered users can track their progress; including the lessons completed, simulations performed, and quiz and tutorial score (Fig. 6).

TEACHER TRAINING AND IMPACT

The E-Foundry resources were initially used within IIT Bombay, to support UG as well as PG courses related to manufacturing that contained metal casting topics. Several best practices evolved, and the 'flipped classroom' pedagogy was fine-tuned. It eventually became possible to structure the casting course around a project, based on an industrial cast part. The students went through the lesson videos on their own, applied the principles to optimize the design of tooling (core, mold) and methoding (feeding, gating) for the selected casting, and verified the same through computer simulation. The casting project was mentioned as the most interesting aspect of the course in their final feedback. These pedagogical experiments were largely possible due to the academic autonomy of the IITs.

Fig. 7. Teacher training programme

The E-Foundry team felt that the best practices evolved at the institute should be shared with teachers in other engineering and polytechnic colleges. Hence a series of one-day teacher training programmes were planned across the country, and conducted in collaboration with interested local institutes. The host institute was responsible for contacting other local colleges, and inviting their teachers of manufacturing subjects to the training programme. Between June-December 2013, seven training courses were conducted at Changa, Indore, Pandharpur, Rajkot, Chennai, Mumbai, and Nagpur, representing four different states in India. About 400 teachers have benefitted so far. More courses are planned at other places. Each training course involved a quick tour of various learning resources, reinforced through computer hands-on session (Fig. 7). The E-Foundry team showed examples of how to use the resources to support theory courses, conduct lab experiments, and explore industry projects.

The teachers trained in the above courses can use the E-Foundry resources and adapt a collaborative model for training and certifying local students. The beneficiaries include current students studying in the host institute as well as other local colleges, graduated students waiting for a job, and working professionals who wish to update their knowledge and software skills. The pedagogy largely relies on self-learning by the student, guided by the local teachers. If needed IIT Bombay faculty are available for clarification of doubts through video conference. At the end of the course (typically one month), there is a three-way assessment of the students: online score provided by E-Foundry, an offline examination by the host institute, and an industrial project endorsed by a local foundry. The Institute of Indian Foundrymen, through its local chapters, is encouraging its member foundries to allow student visits and provide data for their projects.

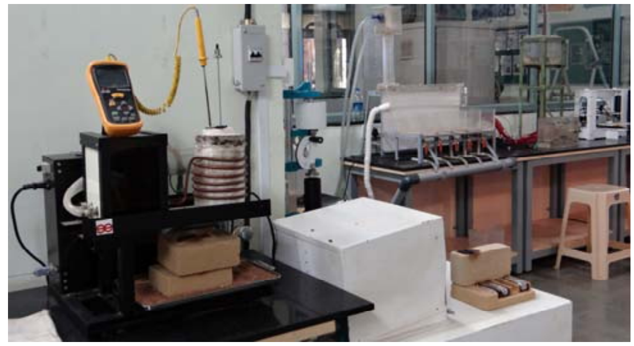

Fig. 8. Tabletop experimental casting facility

The online E-Foundry is complemented by an experimental casting facility (Fig. 8). This includes a low-cost 3D printer for fabricating plastic patterns directly from CAD models, clean molding unit based on 3-part no-bake system, sand mold testing equipment, tabletop induction melter with direct pouring, and temperature data acquisition system for obtaining cooling curves in casting as well as mold. These facilities have been used for a variety of experiments related to molten metal flow, solidification, cooling and dimensional changes, mainly in low melting alloys of aluminum and zinc. Further, transparent molds for observing the flow of coloured water through multi-gate gating system with different positions of sprue, and through different shapes of mold cavities have also been fabricated. The engineering and polytechnic institutes are encouraged to set up similar facilities to further enhance the interest and training of their students in metal casting domain.

It is perhaps still early to assess the impact of E-Foundry initiative. The Analytics engine incorporated in the website provides some useful pointers. Since January 2013, the website has crossed 38,000 visitors and 200,000 page-views. The average time spent by visitors is about 10 minutes. The bounce rate (visitors who leave the site immediately after entering) is less than 6%. Over 10% of the users access the resources through tablets and mobile phones. The number of registered members has steadily increased and now stands at 1650. They have simulated over 4000 castings. Most of the visitors are from India, others are from USA, Brazil, Germany, Italy, Turkey, Mexico, Australia and UK. Within India, most of the visitors are from the locations where the teacher training courses were conducted, as well as foundry clusters. Four institutes where the training courses were conducted, viz., Changa, Indore, Kolhapur and Rajkot, have set up local E-Foundry Cells for conducting regular training programmes for students from their own as well as other local colleges.

CONCLUSION

The twin problems of employment and employability in the manufacturing sector, particularly the metal casting industry, can be addressed by making the subject interesting to engineering students. The E-Foundry initiative is a step in this direction. The teachers in other institutes are empowered by ready access to high quality content in casting design and simulation, exposure to best practices through training programmes, and participation in joint certification. This in turn benefits both students and working professionals, who are able to gain useful knowledge. The initial response is certainly encouraging. Going forward, the E-Foundry team would like to involve other experienced teachers, consultants, and industry experts, and evolve a larger global platform for exchange of knowledge and best practices.

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