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Enhancement of extrusion die learning based on a simulation analysis

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ABSTRACT: Engineering education should permit students to communicate in a manner similar to that of practicing engineers. Engineers use technical writing to explain the design process that they have gone through in their work. This study develops simulation analysis for learning about extrusion dies. Students use Deform3D software and 3D modelling to develop their own applications. Some of the parameter settings that are available to design and integrate the different parts of an extrusion die design are also discussed. Analytical results indicate that experiments supported by DEFORM™3D simulation analysis add to the knowledge and understanding of the material by the students. The results of this study indicate that the proposed laboratory activity is successful. Most students responded positively to these laboratory activities and had no difficulty with the overall activity. Overall student satisfaction with the learning activities was high.

INTRODUCTION

The overall goal of engineering education is to prepare students to practise 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 programmes. Indeed, prior to the emphasis on engineering science, it could be said that most engineering instruction took place in the laboratory [1].

Engineering education places a high priority on laboratory experience. Given that several objectives of engineering education have been discussed [2], laboratories must orient students on how to perform experiments in real or simulated environments.

Computer-based education programmes have been increasingly adopted in schools to supplement or replace traditional teaching methods. Teachers have performed many studies to discern the impacts of new teaching techniques on students' learning abilities. Computer-based virtual simulation is being widely used for the purposes of engineering education. A paper by Georgiev et al presents experiences in building virtual laboratories and provides a discussion of important and relevant issues with regard to the pedagogy, software and equipment utilised [3].

In developing the experimental module for this student hands-on activity, the first goal was to capture and maintain the attention and interest of the student. To make the content attractive, a lot of attention was paid to constructing clear and straightforward ways of introducing teaching concepts. The philosophy of education gains its roots from Piaget's constructivism, which describes a learner as actively constructing knowledge instead of simply receiving knowledge transmitted from teacher to student. Hands-on learning environments are beneficial to student attitudes and learning [4].

Students learn in many ways - by seeing and hearing; reflecting and acting; reasoning logically and intuitively; memorising and visualising; and drawing analogies and building mathematical models, steadily and in fits and starts. Teaching methods also vary. Some instructors lecture, others demonstrate or discuss; some focus on principles and others on applications. Some emphasise memory and others understanding. How much a given student learns in a class is governed in part by that student's native ability and prior preparation, but also by the compatibility of his or her learning style and the instructor's teaching style [5].

What can one say about the individuals needed to function as engineers in the society whose technological characteristics the authors have just outlined? Their profiles may be conveniently sketched in terms of three components:

1. Their knowledge - the facts they know and concepts they understand;

2. The skills they use in managing and applying their knowledge, such as computation, experimentation, analysis, synthesis/design, evaluation, communication, leadership and teamwork;
3. The attitudes that dictate the goals toward which their skills and knowledge will be directed - personal values, concerns, preferences and biases. Knowledge is the data base of a professional engineer; skills are the tools used to manipulate the knowledge in order to meet a goal dictated or strongly influenced by the attitudes [6].

THE EXTRUSION LITERATURE

Extrusion is a complex and sometimes difficult process because tearing tends to occur on the surface of the extradite. The defect is associated with hot shortness and the state of stress when the workpiece goes through the die. It is in turn related to varying amounts of friction in different regions along the die land and also to the existence of a dead metal zone that can cause severe internal material shearing. Recently, the effect of the combination of different deformation processes on extrusion have been investigated:

Bakker et al studied the effect of cold and hot extrusion of equal channel angular pressing (ECAP) processed samples on the microstructure and mechanical properties of pure Al-6101 [7].

Wang et al simulated the three-dimensional (3D) finite element simulation of extrusion, experimental investigation and theoretical analysis [8].

Zhang et al identified the extrusion stem speed as being one of the important process parameters during aluminium profile extrusion, which directly influences the profile quality and choice of extrusion equipment [9].

Mayavaram et al analysed the bearing lengths that produce uniform velocity at the die exit [10]. This is based on a finite element model to solve material flow during extrusion. The solution approach involves iteratively computing velocity, temperature and strain fields during extrusion and updating the bearing lengths until balanced flow is achieved.

THE FINITE ELEMENT MODEL

Rigid-plastic finite element DEFORM™3D software is widely used for simulating the forging, extruding, pulling, rolling, stamping, upsetting and other forming processes of metals. For facilitating the simulation of plastic flow stress, the structure of this software can be subdivided into four modules: pretreatment; simulation engine; postprocessor; and multifunction. The flow stress equation has the following form:

$$\overline{\sigma} = \overline{\sigma}(\overline{\varepsilon},\ \dot{\overline{\varepsilon}},\ T), \tag{1}$$

where T is the temperature, $\dot{\overline{\varepsilon}}$ is the strain and $\overline{\varepsilon}$ s the strain rate.

Currently, the DEFORM™3D system is based on Archard's model and Usui's model, in addition to standard user support. Typically, the Archard's model is widely used for forming applications, and Usui's model is used for machining applications to compute insert wear. Archard's model can be used with either isothermal or nonisothermal runs.

By contrast, Usui's model can be used only with nonisothermal runs, because it requires interface temperature calculations.

For both of these models, the die (or insert, in machining) should be meshed, with appropriate boundary conditions and interobject relations defined. This laboratory will examine the complete problem setup by emphasising the tool wear part of the data and assuming that the user is familiar with the typical problem setup procedures. The formula for the Archard wear model is as follows:

$$Z_{AB} = \int K \frac{p^a v^b}{H^c} dt \tag{2}$$

where Z_{AB} is the wear, *p* is the interface pressure, *v* is the sliding velocity, *H* is the hardness of the tool material, *dt* is the time increment, and *a*, *b*, and *c* are experimentally calibrated coefficients.

SIMULATION ANALYSIS AND LEARNING

The purpose of students' use of the DEFORM™3D software and the 3D modelling is to develop their own applications. The defined activities are at an appropriate level for students. A panel of experts, including experienced researchers, university professors and experienced engineers, evaluated these activities. Extrusion die learning based on a simulation analysis is shown in Figure 1. In this work, a die is designed for the production of this profile, which is shown in Figure 2. An extrusion die is composed of three main parts: a die, a billet and a stem.

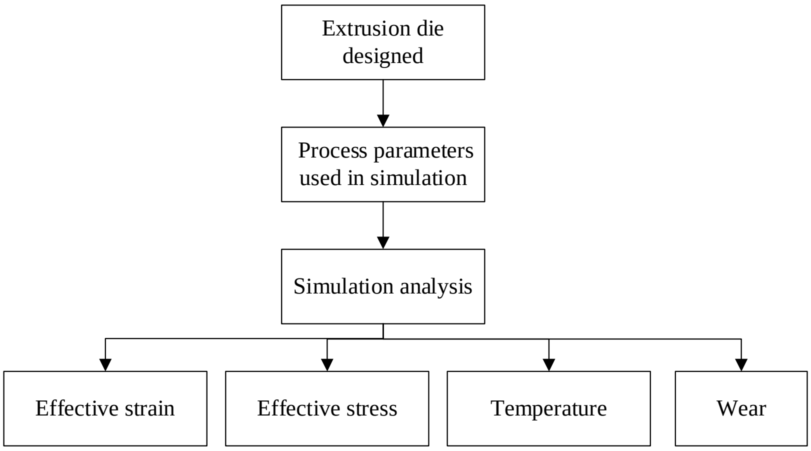

Figure 1: Simulation analysis processing.

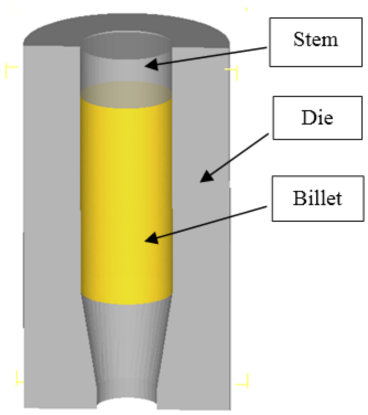

Figure 2: Extrusion die designed.

Figure 3 is a billet meshing of user interface. This simulation was run with multiple steps so that the contact and stresses could stabilise and reach equilibrium. One can play through the steps and observe how the contact changes. The top die contact remains essentially the same throughout the analysis, but the contact on the bottom die changes quite a bit. The applied load pushes the centre of the die downward, causing the outer diameter (OD) of the die to raise off of the support. At the end of the simulation, the contact has stabilised and no longer changes much from one step to the next.

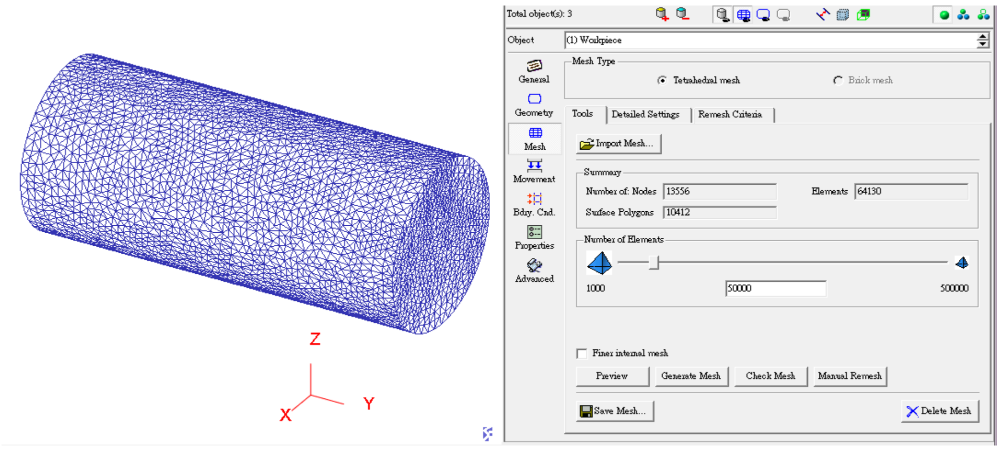

Figure 3: Billet meshing.

The billet used in the simulation is 64 mm^2 in section area. The initial temperature of the billet is 400 °C, respectively. The friction factor between the die and billet material is 0.12. To investigate the effect of the extrusion billet section on the extrusion process, one kind of extrusion section has been listed in Table 1.

Table 1: Process parameters used in simulation.

Section kind of billet	Section area	Temperature of billet	Friction factor
Circular	64 mm^2	400 °C	0.12

Figure 4 is a simulation analysis of the extrusion die. Figure 4a is the die before extrusion, Figure 4b is the middle extrusion and Figure 4c is after extrusion.

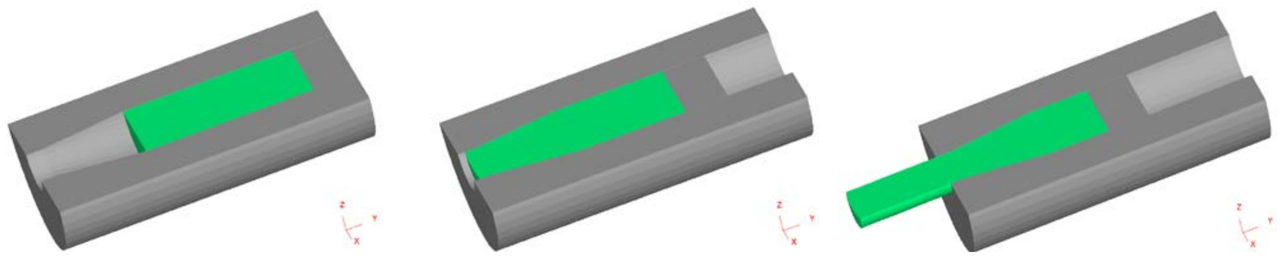

Figure 4: Simulation analysis of an extrusion die process; a) before extrusion; b) middle extrusion; and c) after extrusion.

Figure 5 shows simulation analysis of effective stress of billets extruded. Figure 6 shows simulation analysis of temperature of billets extruded. Figure 7 shows simulation analysis of the effective strain of the billets extruded. Figure 8 shows simulation analysis of tool wear of the billets extruded.

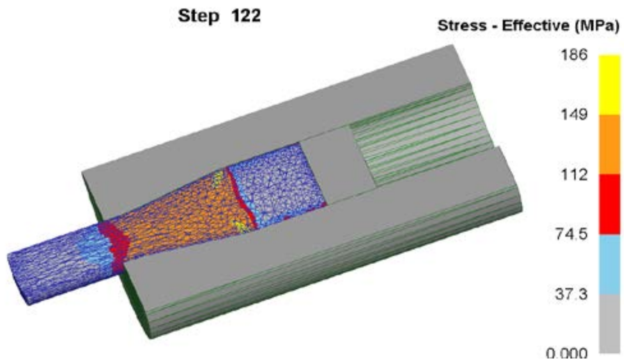

Figure 5: Effective stress of simulation analysis.

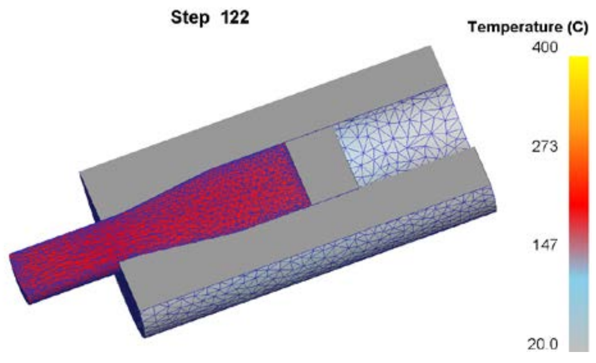

Figure 6: Temperature of simulation analysis.

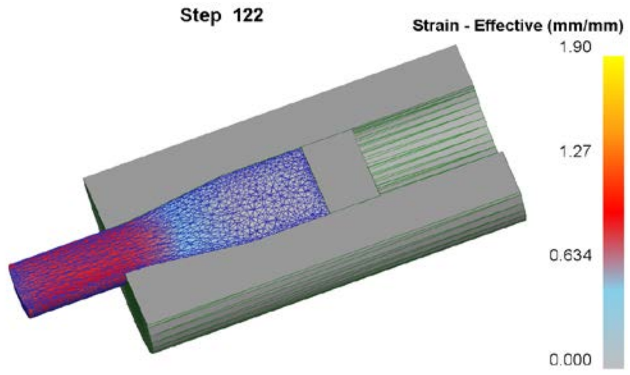

Figure 7: Strain effective of billets extruded.

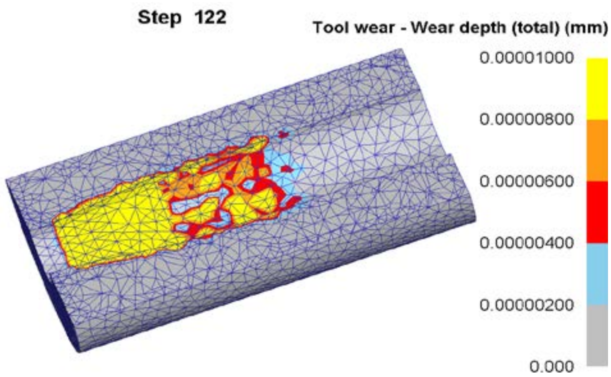

Figure 8: Simulation analysis of tool wear.

The *max* and *min* effective stresses are graphed for each billet. It can be seen that at the end of the simulation, when the contact is no longer changing, the stresses stabilise and do not change any further.

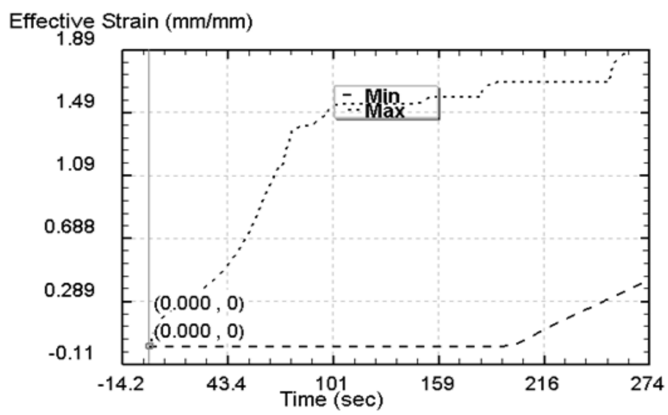

Figure 9: Relationship of effective strain and time.

Figure 9 shows the evolution of required extrusion effective strain in terms of the billets. The maximum effective strain of die and stem between 0 to 101 seconds at the billet effective strain can be observed. The required extrusion time increases, the billet effective strain is reduced at a relatively steady state.

LEARNING ASSESSMENT OF THE EXTRUDED COURSE

Assessment is utilised in order to elevate the standards in terms of teaching, learning and student achievement. Assessment quality has a marked impact on student willingness to work hard and encourages teachers to focus on ways of improving individual learning attitudes. Students responded to questionnaire items on a Likert scale ranging from 1 for *strongly disagree* to 5 for *strongly agree*.

This study also develops a laboratory activity for helping college students to learn about extrusion, including practices and applications. This course has a total of 20 students. The results of this study indicate that the proposed laboratory activity is successful. Most students responded positively to these laboratory activities and had no difficulty with the overall activity. Overall student satisfaction with the learning activities was high.

Table 2: Survey results of extruded course.

Evaluation items	M
1. Background information was clearly written	4.31
2. Course was challenging and interesting.	4.21
3. Materials were helpful in the course.	4.10
4. There were enough practice sessions.	4.15
5. Key terms were explained, understandable and useful.	4.51
6. This course enables me to experience more about the knowledge extruded.	4.25
7. I will recommend this course to other students.	4.31

CONCLUSIONS

Engineering education should permit students to communicate in manners similar to those of practising engineers. Engineers use technical writing to explain the design process and they use it through in their work. The interview for this technical writing is someone with background knowledge in the area being addressed. In addition, engineers need to be able to communicate their technical ideas in common language for those without an applied science background.

DEFORM^{TM}3D is a simulation analysis software package for extrusion dies, and it has been successfully used in industry. Students can adapt the software during classes and at home, to control the simulation process, and to learn about the extrusion die concepts that will be helpful in their professional careers.

Survey results reveal a favourable opinion among the students participating in the course. Importantly, the students in this study were generally curious about and receptive to, these activities. The students participating in these laboratory activities found them to be extremely informative and enjoyable. There is no difficulty in learning.

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