A New Course on ‘Welding Engineering and Design of Welded Structures’ to Better Train Engineering Graduates for The Future

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INTRODUCTION

Welding is one of the more common methods of joining to create useful structures. It is commonly used in ground, marine and air transportation equipment, bridges, pressure vessels, machines, etc. Welding is a complex process and one of the most essential processes for the economy of any nation. It is one of those processes which enables industries to be set up, agriculture to thrive, power generation, and reliable communications, among a host of applications.

An optimum and reliable design of a welded structure requires an integrated approach to understand welding processes, materials science, fatigue design, joint failure, experimental mechanics, and inspection. Hence, the total design of a structure involving welding as one of the joining methods needs an integrated and interdisciplinary approach. Figure 1 shows the large number of variables involved in the design of a safe welded structure.

Today, examples abound which show the need for engineers and scientists who have an integrated, interdisciplinary background bridging mechanics, materials science, manufacturing, and design. Consider, for example, the High Speed Civil Transport (HSCT) vehicle, the international space station, or the future automobiles. All of these applications involve joining (welding) of a host of dissimilar or similar materials.

It may be noted that though knowledge of welding engineering and design of welded structures is central to the optimum and reliable fabrication of a large number of critical structures, to the best of my knowledge, almost all the mechanical engineering curriculums in the country do not even remotely address this issue. The proposed course will bridge different aspects of mechanics, materials science, metallurgy, manufacturing, and design. It will train the students to think critically in designing welded structures and in other design situations, and will enhance their overall design experience.

This paper presents the philosophy and the course contents of the newly proposed course. Also links between mechanics, materials science, manufacturing, and design, using modern multimedia and instructional technology, in the context of teaching prospective engineers how to approach the total design of a welded structure are presented.

OBJECTIVES

Advancements in certain critical technology areas will require engineers who have an integrated knowledge of applied mechanics, materials science, manufacturing, design, and computer technology. This paper seeks to build upon the linkage between the above-mentioned disciplines in a course on Welding Engineering and Design of Welded Structures by:

1. Creating courseware for use at the upper senior level and developing it further by taking advantage of recent innovations in scientific research and instructional technology;
2. Laying the foundation for developing a new graduate course that provides for an integration and synthesis of mechanics, materials technology, manufacturing and design;

CURRICULUM DEVELOPMENT

The new course seeks to emphasize on the relationship between applied mechanics and materials science while teaching the science of welding and the total design of welded structures. As will be evident from the course content, it is an interdisciplinary course covering areas of mechanics, materials science, metallurgy, manufacturing, and design.

Course Development:

The selected contents of the new course are given below:

Welding Engineering and Design of Welded Structures (Senior Level, 3 credit hours)

Theory:

- Intro. to Joining Techniques: Welding, Fasteners, Adhesives
- Welding Processes
- Solidification in Welds
- Metallurgy of Welding
- Design Considerations for Welded Structures
    - types of welds
    - joint design
    - stresses in welds
- Intro. to Linkage Between Atomic Structure & Mechanical Response of Materials
- Theories of Fatigue: stress and strain based
- Fatigue of Welded Structures
- Fracture of Welds
- Control of Shrinkage and Distortion in Welds
- Corrosion in Welds
- Weld Defects and Inspection of Welds
- Case Studies

Laboratory (demonstrations only):

- Intro. to optical experimental methods of materials characterization (e.g., moire interferometry and photelasticity)
- Mechanical testing of welded specimens – tension, bending, torsion
- Quasi-static and dynamic testing of spot welds
- Effect of corrosion on tensile, bending, and torsion strength of weld

The course starts of with an introduction to the atomistic view and physics of welding. Then an overview of the various welding processes is provided. The student is then introduced to solidification theory of metals and the metallurgical aspects of welding are presented using the Jominy bar end-quench test (ASTM A255 and A304). A one-dimensional heat transfer model is used to simulate the heat flow in a Jominy bar and the temperature profile is developed and related to the phase diagrams. Then a two-dimensional heat transfer model in a plate with a heat source is developed. This problem models fusion welding of a plate. Solidification and phase changes are followed in the fusion zone, partially melted zone, and the heat affected zone. The effect of microstructure of phases on the mechanical properties in various zones is introduced. The effect of the microstructure on the fracture and fatigue behavior is also introduced. Then the students are introduced to the design of welded joints such as fillet welds, butt welds, and circumferential welds, in a variety of structures. At this stage they determine the stresses in the welded joints, design the joints keeping in view the strength, fatigue, and fracture requirements, and also specify the most optimum welding process. The course ends with an introduction to residual stresses and weld distortion, corrosion in welds, and weld inspection.

***Multimedia Courseware**:*

It is envisaged to use enhanced computer imagery or a multimedia approach to visually demonstrate the intimate relationships between macroscopic mechanical phenomena and the associated micro-mechanisms during deformation and failure in welded joints in structures, and the metallurgical transformations during welding and post treatment, such as crystallization and grain growth during solidification and heat treatment. Eventually the information will be disseminated to the students and a selected professional community through text, CD-ROM, and the Internet. In addition, this courseware will facilitate active student learning, and reduce reliance on traditional lecture methods of knowledge delivery.

More specifically we will investigate establishing the above mentioned relationships for mechanical behaviors of welded joints such as elastic deformation, plastic deformation, fatigue, and fracture etc. in ferrous and non-ferrous materials used in structures.

As an example, consider a welded joint in a ductile metal (say, low carbon steel) as it is loaded through the elastic and plastic region all the way to fracture. Typically students with a mechanics of materials background will analyze the problem by determining the stress level at yielding and fracture and determine the appropriate factors of safety needed in the use of the joint. They will seldom look for a correlation between the parameters of yield, fracture, toughness, and ductility, and the atomic structure of the material, dislocation movements, slip planes, grain structure, fracture mechanisms, etc. Through an interactive multi-media course, with detailed diagrams, pictures, and explanations, it is intended to bridge this gap, and provide a medium to enhance their grasp on the subject.

This paper presents only one module, namely 'mechanical behavior of a welded joint under tensile loading'. This module will describe the deformation response on the basis of atomic- and macro-level mechanisms, the stresses generated, and the failure mechanics of the welded joint.

The tensile test of a joint is one the most important and fundamental tests for determining material properties. Thus a multi-media based module will be developed in the Authorware software environment (Macromedia Inc.). This course module will highlight the links between the fundamentals of materials science, mechanical engineering, and its usefulness in generating design information.

The 'tensile response of a welded joint' module will include:

- a multimedia presentation of a tensile testing machine
- a multimedia presentation of the different types of welded tensile test specimens
- the stress-strain diagram for a welded joint under tensile loading
- a discussion of the data that can be acquired from the test
- discussion on the evaluation of material properties from the tensile test data
- detailed reviews of the link between atomic structure and materials deformation in the welded region under the action of external loading. The reviews may include topics such as introduction to link between atomic structure and materials behavior, atomic bonding, crystal structure, atomic basis for elastic and plastic deformation, metallurgical aspects of solidification and resulting microstructure in the welded regions, defects due to the welding process, and fracture in the heat affected zone of the weld joint
- drill questions and exercises

It is believed that this approach will considerably enhance the understanding of constitution of the weld and its mechanical behavior under different loading conditions, and pave the way for advances in safer and optimum design of machines and structures.

The above-mentioned example module will be generated using a multimedia-based combination of hierarchical and linear structure to lead the student through the links between the mechanics and materials science, and automatically prompt the user to look at different aspects of the relationship. A hierarchical and linear structure is used when very structured but linear documents are put on-line. It may also be noted that images will consist of both inline and external images. Inline images are images that appear directly on the web page and are loaded when one loads the page. These images should preferably be in GIF format All Web browsers display GIF files, though some newer browsers also display JPEG files. External images are those that are not directly displayed when the page is loaded. They are only downloaded at the request of the user. Because browsers can be configured to handle different file types, and helper applications can be used to display many different image formats, we will have more flexibility in the kind of image formats we can use for external display, for example JPEG, PCX, PICT, and MPEG Video.

Pros and Cons of Multimedia Based Instruction: Multimedia courseware described above is intended to increase student learning and teaching efficiency. The courseware will be designed so that the students are motivated to learn and use the software with a resulting increase in performance. Many different and complex considerations go into a useful design of multimedia teaching tools (Davies and Crowther, 1995). Careful consideration will be given to the quality of the material in the multimedia courseware so that it is intellectually stimulating and provide positive motivation to learn. According to Russ (1994) the students' motivation will be related to their expectation of being able to successfully work through the multimedia package and how they expect to benefit from the process. Hence the instructor will duly inform the students about the relevance of the courseware and the exercises.

The multimedia courseware will promote active learning by actively engaging the student in the subject matter. This will be achieved by using a variety of questions, exercises, and discussions. The courseware will have built in questions, problems, and tests, which encourage thinking and action on the part of the student. The interactive capabilities of the multimedia will be used to ensure that the student performs the desired learning activity. This will be achieved by allowing progress through the package only if the student completes a set of required tasks. Also the possibility of posing different problems to different students exists. This interactive capability of multimedia sets it apart from conventional lectures where it becomes very difficult for the instructor (except in very small groups) to check each student's engagement in the desired activity in a desired manner.

The courseware will be designed so that it provides feedback to the student, so that they can assess their own progress and understanding. The courseware can be made to adapt to the student's responses, so that the activities can be geared to the particular interests and abilities of the individual. Such one to one interaction (or tuition) is very difficult in a traditional lecture. However, care will be taken that we do not include too many problems to make it tedious to work through the package.

Multimedia courses promote experiential learning, by enabling the students to do for themselves. According to Klob (1984), experiential learning is one of the four key elements of learning: planning, experiencing, reflecting, and theorizing. Multimedia through the use of sound and video can simulate reality and thus facilitate experiential learning. The student makes decisions and can see the consequences of those decisions. In this way we facilitate a student's learning and the student has to take a major responsibility for his/her own learning. This approach is termed as 'student centered learning' based on the work of Rogers (1951).

Thus the proposed multimedia courseware will be designed to facilitate and promote student learning, and not merely to translate the traditional lecture into a computer environment. It may be noted that the multimedia course is not to replace the lecture. The student will have the flexibility to choose what is studied, when it is studied, in what order, and at what pace. Never the less, the instructor (or a teaching assistant) will be available at designated times to assist the students if help is needed. The instructor will now become not only a transferor of knowledge but also a facilitator of student learning.

Beyond subject specific objectives, mentioned above, other important skills in the education process include communication, analytical, interpersonal, quantitative, synthesizing, problem-solving, and evaluative skills. Some of these skills will be achieved through the use of interactive multi-media case study projects, which will provide a basis for possible group work, report writing, oral presentation, problem-solving, and quantitative skills.

COURSE EVALUATION

The course was taught for the first time in Spring 2000 semester. And at this time very limited data is available with regard to assessment of the course. The students reported that the class was very useful to them and it generated great interest from the industries at which they were seeking employment. The course outline and philosophy was also presented to the Industrial Advisory Board. The board members from the manufacturing and service industries were very receptive to the idea and showed great interest and support for such a course. Further details planned for the evaluation of the course when taught again in Fall 2002 are given below.

Evaluation of curricular development is challenging, due to lack of clear agreement on suitable metrics, and insufficient data for comparisons. However, several resources are available to guide the way in developing an evaluation plan [e.g., see Angelo and Cross, 1993; Herman, 1987; Rossi and Freeman, 1993; Stevens et al., 1993; Worthen and Sanders, 1987].

To begin, student learning will be assessed through two evaluation methods. First, the class will be divided into small *focus* groups of up to 5 students, and each group will be provided with a set of very specific questions [Stewart and Shamdasani, 1990]. Each group will discuss among themselves and then all the groups will discuss the findings of each group to build a consensus. Sample questions may address: how easy it is to surf through the web page linking macroscopic mechanical behavior to micro-mechanisms in metals, deformation and shrinkage control in weldments, what did you like best about the graphics and textual explanations, have you understood all deformation mechanisms in metals, can you now explain these to another person, etc. Responses to the focus group questions, as well as comparisons of their answers on homework and examinations, will be compared to control groups who have not used the newly developed materials. Sampling will typically be done at the beginning, middle, and end of each semester.

The second evaluation will consist of individual performance on a "Baseline Test". We will follow the work of Hestenes and Wells [1992] and Hestenes et al. [1992] (i.e., their "Mechanics Baseline Test" and "Force Concepts Baseline Test"), in order to develop my own instruments which assess quantitative and qualitative student understanding of basic concepts in mechanics of materials. The test will be administered at the beginning and end of each semester, and comparisons will be made within the new course/multimedia structure, and between groups of students taking the new and traditional methods of teaching these subjects. One primary goal of the first evaluation will be to obtain feedback that can be quickly implemented, while the second evaluation will assess individual learning.

The students completing this course will be tracked in other mechanics courses with regard to their performance, percentage of students using such principles in capstone design projects, undergraduate research, and percentage of students pursing graduate studies in such areas. Thus, the total impact of the developed curriculum will be known clearly over a span of about 4-5 years.

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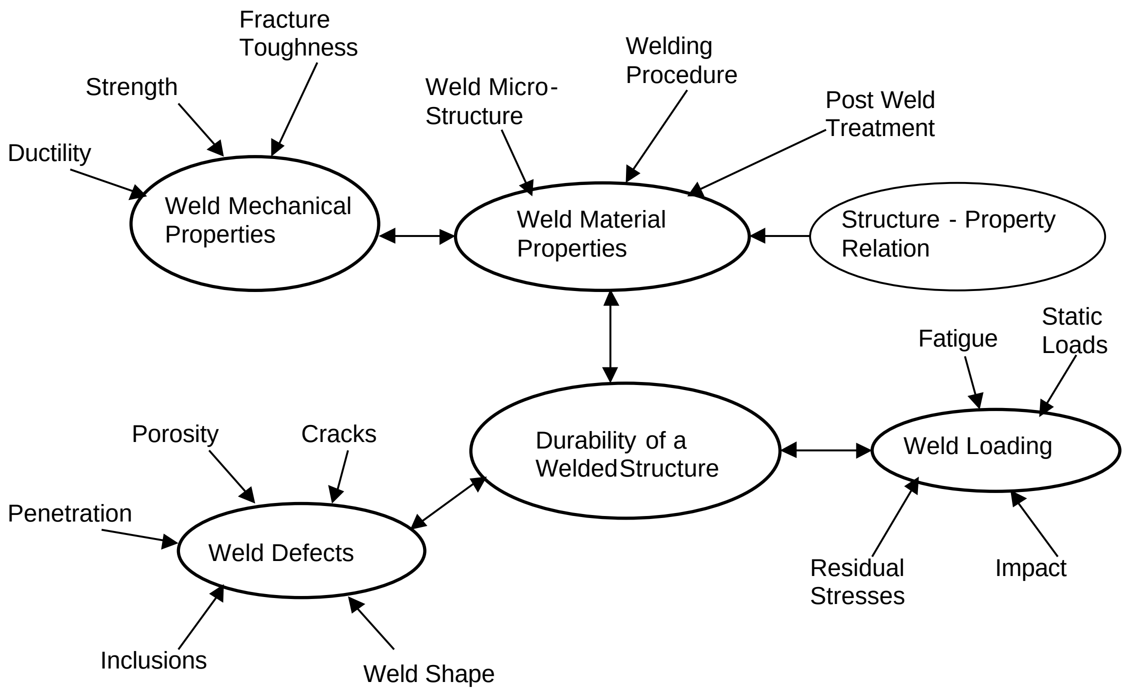

Figure 1. Variables that influence the durability of a welded structure