Advanced Steel Welding Metallurgy – Hybrid Course Spring 2018

This is a new hybrid course **(14 weeks online, 1 week on campus), which will be taught in English** by an American welding engineering professor (Dr. Yoni Adonyi, LeTourneau University, Texas), with help from a Hungarian professor (Dr. János Dobránszky, Budapest University of Technology and Economics).

The approx. 45 contact hour course is asynchronous and will follow the **2018 Spring semester** time table. With parallel registration in the US and Hungary of a mix of working professionals and graduate students enrolled, increased learning can be expected from student-to-student interactions. The course will give European students a good insight in the working of the American Welding Society too.

The content is aimed at Graduate level and might require 15-20 hours/week of intense studying – lectures, discussion board, homework, quizzes. Participation in the **campus labs and exams week is mandatory**, with over 40% grade depending on its success. One such equivalent weeks of labs, projects and final exam will be offered: *Budapest, end of June 2018*.

In case students would chose to travel abroad, travel expenses will not be included in the course fees - see attached syllabus with details and course outcomes. However, lodging and meals in Longview will be provided at student discount rates.

Prerequisites are a BSc degree in Engineering from an accredited university and proof of advanced proficiency in English. A certificate of completion will be issued for those with a passing grade, bearing signatures from LeTourneau University, Longview, TX and BME, Budapest, Hungary. This course would complement in content the knowledge gained during the European Welding Engineer (EWE) course.

Advanced Steel Welding Metallurgy, SP 2018

GENERAL: This hybrid graduate-level course is to be delivered in 14 online weeks and one on-campus lab and project experience, as detailed below. The course is to be taught in English, but Hungarian faculty is expected to moderate individual students and groups online under special Discussion Board forums.

The Blackboard® online teaching system will be used for the course delivery and each student should use their tutorial to learn its use before the classes start.

Each week, the topics included in a video lecture and reading material should be studied and a weekly quiz should be taken and homework completed. Additionally, each student is expected to make a meaningful entry on the Question of the Week Discussion Board and interact with his/her peers online for a Semester project. Students should expect to spend 10-15 hours/week on their own time to accomplish these tasks.

After the Midterm exam, students with who fall behind will be individually tutored, as needed. The Final Exam is to be taken during the on-campus week, when lab exercises and project presentations are also to be completed. Grading is listed at the end of this syllabus.

COURSE OUTCOMES

At the end of this course, the students should:

1. *Explain* modern steel manufacturing technologies and the metallurgical principles behind most strengthening mechanisms used, with emphasis on modern AHSS and HPS steels.
2. *Evaluate* the effects of weld thermal cycles and steel base metal/filler metal composition on the resulting fusion- and heat affected zone properties.
   a. Apply hardenabililty (carbon equivalent type) predictive equations to find minimum preheat and interpass temperatures to avoid *hydrogen induced cracking*
   b. Apply *solidification cracking* predictions to optimize filler metal composition, dilution and heat input and avoid cracking.
   c. Apply *reheat cracking* susceptibility, use predictive equations and simulated weld testing to avoid it.
3. *Differentiate* between- and understand the relationship with service-induced fatigue and corrosion-fatigue cracking mechanisms from the above three manufacturing cracking.
4. *Recognize Fitness For Purpose* (FFP) design and service performance concepts and the relationship between metallurgical (pre-existing) cracks on long-term fatigue- and brittle failure – as opposed to plastic collapse and Safety Factor classical concepts.
5. *Assess* the applicability and limitations of steel welding codes such as AWS D1.1, D1.5, API 5L and ASTM Section IX.
6. *Perform* metallography, optic and electron microscopy.

Textbooks

1. Callister, W.D., "Material Science and Engineering, an Introduction", 8th edition, ISBN 978-0-470-41997-7, www.wiley.com/college/callister
2. Kou, Sindou, "Welding Metallurgy", 2nd Edition, ISBN 0-471-84090-4
3. Barsom, Rolfe, Failure and Fracture in Steel Structures ISBN 0-13-329863-9
4. Messler, R. –"Principles of Welding" ISBN 0-471-25376-6

Weeks/Topics

1. Materials Science fundamentals overview: Metals vs. other Engineered Materials (Polymers, Ceramics, Composites)

i. Weekly Objectives:
- Communicate course structure, expectations, Introductions, organizational issues
- Differentiate between metals and other engineering materials based on interatomic bond types, crystalline vs. amorphous, isotropy vs. anisotropy
- Understand the relationship between chemical bond types (nanoscale) and mechanical properties (macroscale)

ii. Assessments:
- Quiz # 1
- Discussion questions, Week #1
- Homework set # 1, Cal. 2-14, 2-16, 2-10, 3.7
- *DUE: Personal Homepage, Blackboard Roster. Include current expertise and access to welding/joining equipment at work*

iii. Learning Resources:
- Animation – metal at an atomic level (atomic bonds)
  - Metallic bonds (excerpt) - http://youtu.be/XHV9LzCH2KA
  - Other Chemical Bonds, Ionic vs. Covalent; www.youtube.com/watch?v=7DjsD7Hcd9U
  - Lecture videos – Lecture videos # 1
- Readings:
  - Ch. 1,2 and 3, Material Science (Callister)
  - Knovel, Link #1

2. **Ferrous Metallurgy Fundamentals, review of Extractive, Chemical and Physical metallurgy, ingot vs. continuous casting, Heat treatments**

   i. Weekly Objectives:
   - Identify the principles extractive metallurgy and steelmaking.
   - Differentiate between various manufacturing (blast versus electric furnace), casting (ingot versus continuous), and rolling (hot versus cold) practices.
   - Identify the principles of heat treatments, plate, tubular and sheet products.
   - Recognize the microstructure/property relationship in carbon and low alloyed steels.

   ii. Assessments:
   - Quiz #2 (questions from textbook and custom created questions; M/C, T/F, and essay questions)
   - Weekly Discussion Board #2, Use Cal. 11.1, 11.25, Electric Arc vs. Blast Furnace
   - Homework set #2 Cal. 11.D6 and 11.D13
   - *DUE: Grouping students in Project teams using Personal webpage info.*

   iii. Learning Resources:
   - Lecture videos –
     - Lecture Videos #2
   - Readings:
     - Ch. *11, Material Science (Callister)*
   - Supplemental videos:
     - Royal Society of Chemistry (RSC) Iron and Steel - http://youtu.be/xAVCY0WE8uM
     - US Steel, integrated steelmaking, CONTINUOUS casting http://www.youtube.com/watch?v=9l7JqonyoKA
     - Alloy Steel and Steel Components, Electric Arc Furnace, INGOT casting - The Timken Companyhttp://www.youtube.com/watch?v=QXcbM13x7Ew
     - http://youtu.be/8l-Wrlpl7V8

3. **Steel strengthening mechanisms and phase transformation phenomena**

   i. Weekly Objectives:
   - Differentiate between solid solution strengthening, dislocation- and precipitation hardening.
   - Identify points and lines on phase diagrams, equilibrium solidification, eutectics, and liquation.
   - Differentiate between diffusion-driven and diffusion-less transformations.
   - Be familiar with concepts such as thermodynamic equilibrium, phase transformations, solidification in metals

   ii. Assessments:
   - Quiz #3
   - Weekly Discussion Board #3 – Complex Phase 1500MPa welding
   - Homework Set #3, Cal. 10.13 and 10.14

   iii. Learning Resources:
   - Lecture videos –
     - Videos # 3
   - Readings:
     - Ch. 3 of *Welding Metallurgy (Kou)*
     - Ch 7, 9, 10 Material Science (Callister)

4. **Solid-Gas and Metal-Gas reactions, Diffusion in solids, hydrogen-induced cracking**

   i. Weekly Objectives:
   - Explain atomic gas diffusion in metals, solubility in liquid and solid state.
   - Summarize oxidation activity, Ellingham Diagram, deoxidants, Prof. Granjon's explanation of hydrogen induced cracking in welds.

ii. Assessments:
- Quiz #4
- Weekly Discussion Board #4 – delayed cracking scenario
- Homework Set #4, Cal. 5.15, 5.D3
- DUE: Team Project Proposals

iii. Learning Resources:
- Lecture videos –
  - Lecture Video #4 – Preheat, Hydrogen sources, delayed cracking
  - Hydrogen evolution video, UT Delft, LETU
- Readings:
  - Ch. 4 of *Welding Metallurgy (Kou)*
  - Ch.*5, Callister*

5. Non-equilibrium solidification, segregation, constitutional supercooling, solidification cracking

i. Weekly Objectives:
- Differentiate between equilibrium and non-equilibrium solidification, segregation, and super-cooling.
- Explain solidification morphology, dendrite growth rate vs thermal gradient, weld pool shape effects.

ii. Assessments:
- Quiz #5
- Weekly Discussion Board #5 – Laser beam vs. GTAW weld cracking
- Homework Set #5

iii. Learning Resources:
- Lecture videos –
  - Lecture video #5
  - Oak Ridge National Labs video
- Readings:
  - Ch. 5 of *Welding Metallurgy (Kou)*

6. Post-weld precipitation hardening, reheat cracking, predictive equations

i. Weekly Objectives:
- Apply concepts of residual stresses, distortions, Thermal treatments to Cr-Mo steels.
- Calculate reheat cracking parameters.
- Differentiate between various validation testing procedures.

ii. Assessments:
- Quiz #6
- Weekly Discussion Board #6 – Cr-Mo pressure vessel PWHT cracking scenario
- Homework Set #6

iii. Learning Resources:
- Lecture videos –
  - Stress relief cracking
- Readings:
  - Ch. 7 of *Welding Metallurgy (Kou)*

7. Arc welding, net heat input, Heat Affected Zone transformations, hardenability, preheat calculations (MIDTERM posted online)

i. Weekly Objectives:
- Explain heat transfer and melting efficiencies and connections with CCT diagrams, Jominy bar testing.

- Identify the applicability and calculate carbon equivalencies.

ii. Assessments:
- Quiz #7
- Weekly Discussion Board #7 – Spiral SAW vs. orbital GMAW pipe welding
- Homework Set #7

iii. Learning Resources:
- Lecture videos –
  - Lecture Video #7
- Readings:
  - Ch. 6 of *Welding Metallurgy (Kou)*

8. MIDTERM, Reviews, Discussions of mostly misunderstood topics, Overview of welding processes

i. Weekly Objectives:
- Review MIDTERM test performance.
- Differentiate between solid-state and fusion welding processes.

ii. Assessments:
- MIDTERM ONLINE (single attempt, 2-hours, closed book, over a 4-day period)

iii. Learning Resources:
- Lecture videos –
  - Lecture video #8
- Readings:
  - Ch. 6 of *Principles of Welding (Messler)*

9. Plane stress vs. plane strain, plastic collapse vs. brittle failure, Ductile to Brittle transition Temperature, impact- (Charpy) vs. fracture- (CTOD) toughness in welds and HAZ

i. Weekly Objectives:
- Describe weld integrity vs performance, post weld transformations.
- Clarify temperature and strain rate effects, impact and fracture toughness.

ii. Assessments:
- Quiz #9
- Weekly Discussion Board #9 – comments on Midterm
- Homework Set #9…
- DUE: Semester Project Progress report# (Team report)

iii. Learning Resources:
- Lecture videos –
  - Lecture Video # 9
  - Fracture and Failure, TWI video
- Readings:
  - Ch. 1, 2, Barsom and Rolfe
  - Ch. 8, Callister

10. Welding Codes and Specifications

i. Weekly Objectives:
- Explain the origins of laws, standards, codes, and specifications.
- Differentiate between consequences of violating laws, standards, and codes.
- Clarify the authority and responsibility of the individual applying the standards. (use AWS D1.1 as example)

ii. Assessments:
- Quiz #10
- Weekly Discussion Board #10 – use of AWS D1.1 vs. ASTM Section IX

- Homework Set #10

iii. Learning Resources:
- Lecture videos –
  - Lecture Video #10
- Readings:
  - AWS *D1.1 and D1.5*
  - ASTM *Section IX*
  - API *5L*

11. Analytical techniques: destructive- vs. nondestructive testing of steel welds

i. Weekly Objectives:
- Explain sample size and strain rate effects on static destructive testing (tensile, bend, compressive) as well as dynamic (fatigue) testing.
- Identify the six nondestructive (NDE) techniques and correlations with destructive test results.

ii. Assessments:
- Quiz #11
- Weekly Discussion Board #11 – Mechanical test "trust" scenario vs. NDE
- Homework Set #11

iii. Learning Resources:
- Lecture videos –
  - Lecture video # 11
  - Intro to NDT, an ASNT video
- Readings:
  - *Introduction to NDE*
  - *Destructive testing*

12. Weldability testing; simulated, small-scale, full scale

i. Weekly Objectives:
- Explain the principles of self-restraining vs. external restraint.
- Explain the sources of variability in test results.
- Interpret data of cold-, warm- and hot cracking assessments.

ii. Assessments:
- Quiz #12
- Weekly Discussion Board #12 – Compare hot cracking weldability tests
- Homework Set #12

iii. Learning Resources:
- Lecture video
  - Lecture Video #12
- Readings:
  - Ch. 15 of *Welding Metallurgy (Kou)*

13. Case studies: failure analysis, lessons learned

i. Weekly Objectives:
- Assess the most common failure types (plastic collapse, brittle failure, fatigue and corrosion-fatigue).
- Explain the analysis steps, extraneous factors, legal aspects, and consequences of misdiagnosis in failure analysis.

ii. Assessments:
- Quiz #13

- Weekly Discussion Board #13 – comments on Stud welding Failure report
- Homework Set #13

iii. Learning Resources:

- Lecture videos –
  - Narrated video: Failure in Steel Structures, TWI
- Readings:
  - Ch. 2*Barsom, Rolfe,*
  - *Ch. 8, Callister*

14. Preparation for On-Campus labs (overview of the lab equipment and how the practicum week will be structured)

i. Weekly Objectives:

- Prepare students for all lab exercises
- Explain metallography and non-destructive testing.
- Clarify reporting requirements, examination procedures
- Discuss living arrangements and extracurricular activities

ii. Assessments:

- Quiz #14 – on metallography and non-destructive testing
- Discussion Board – answer questions, comments on assessments, general

iii. Learning Resources:

- Lecture videos –
  - Welding arc Plasma
  - Metallography techniques
  - Lecture #14 – Metallography Instructionals
- Readings:
  - *Practical Metallography*
  - *Ultrasonic and Eddy Current testing*
  - *Arc and power beam processes*

15. On-Campus labs, exercises, reports, FINAL test

i. Day 1 – Introductions, Safety, Lab tour, demos

- Metallography, optic and electron microscopy (MET)*
- Welding processes, hands-on training (WE*
- Fractography, failure analysis (FA)*
- Intro to non-destructive testing (NDE)*

ii. Day 2 – Diffusible hydrogen, preheat, delayed cracking

- Comparative cracking evaluations
- Practical Ultrasonics and Eddy Current testing

iii. Day 3 – FINAL EXAM

- Semester Project Presentations, Individual Reports due
- Numerical Analysis, COMSOL and ABAQUS
- Physical simulations

iv. Day 4 – Final Exam Discussions,

- Solidification cracking, Gleeble testing

v. Day 5 – Liquation cracking, Varestraint testing,

- Lab Makeup sessions
- Opportunity to take an optional ORAL EXAM
- Course Evaluation Survey

	TEAM 1*	TEAM 2	TEAM 3	TEAM 4
Day 1	Safety MET	Safety WE	Safety FA	Safety NDE
Day 2	WE	FA	NDE	MET
Day 3	FA Final Exam, Presentations	NDE Final Exam, Presentations	MET Final Exam, Presentations	WE Final Exam, Presentations
Day 4	NDE	MET	WE	FA
Day 5	Makeup Oral exam, Course Evaluation survey	Makeup Oral exam, Survey	Makeup Oral exam, Survey	Makeup, Oral exam, Survey

GRADING

Midterm	Weekly Discussion Board Entry:	5%
	Weekly Quiz:	10%
	Homework:	10%
	Online Project*:	10%
	Midterm Exam:	65%
Final	Weekly Discussion Board Entry:	5%
	Weekly Quiz:	10%
	Homework:	10%
	Online Project:	15%
	Lab Reports	15%
	Final Exam:	45%

*Same teams as in Semester Projects