

Spring 2020 (offered as WELDENG 7193.02, class number 6845—no online offering of this course in SP20)

Instructor: Dr. Alexander E. Shapiro

Course Objective: This course continues the education in brazing and soldering discussed in the introductory course 4023/7023. The course includes deeper consideration of such fundamental concepts of brazing and soldering processes as capillary flow and wetting of solids by liquid filler metals. Additionally, the course discusses the following aspects of physical metallurgy: (a) Physical-chemistry of liquid-solid interface and interfacial reactions on metals or ceramics, (b) Reactive wetting of ceramics, (c) Formation of solid solutions, eutectics, and intermetallics in the joints, (d) Diffusion in brazing and soldering, including kinetics and diffusion exchange between solid and liquid metals, (e) Erosion and dissolution of base metals in the liquid filler metals and liquid embrittlement.

Practical aspects are discussed in this course in conjunction with the above-mentioned fundamentals and include: (f) Design of brazing alloys, (g) TLP process, (h) Strength of brazed and soldered joints: a model of a multilayer composite material, (i) Joint's reliability by margins of safety approach (j) Hot strength, creep resistance, and fatigue of brazed joints, (k) Methods of mechanical testing of brazed joints.

The third block of lectures covers brazing and soldering of such advanced materials as refractory metals, ceramics, ultra-hard materials, optical glass-ceramics, and other. All lectures include practical case studies.

Prerequisites: WE4023/7023

Textbooks:

- (1) Brazing Handbook, 5th Edition, 2007 or 6th Edition, AWS, Miami, FL
- (2) Paul T. Vianco, Soldering Handbook, 3rd Edition, 1999, AWS, Miami, FL
- (3) Humpston G., Jacobson D. Principles of Brazing & Soldering, ASM International, 1993
- (4) Eustathopoulos N., Nicholas M. G., Drevet B. Wettability at High Temperatures, Pergamon, London, 1999

Lecture Notes: Advanced Metallurgy for Brazing and Soldering, Copyright 2019, Alex Shapiro

Teaching Approach: All lectures are recorded live (slides & audio) and posted on Carmen. Recorded lectures from previous years also available.

Time and Location: Friday, 2:15 p.m. – 5:00 p.m. 111 EJTC.

Grading:

Midterm	30%
Labwork 1 report	30%
Final	40%

Reference Texts and papers posted on the course website for additional reading:

- (1) Cahn R. W., Haasen P. Physical Metallurgy, 1-3 volumes, 1983, NHC, Oxford, UK
- (2) Seitz F., Physics of Metals, McGraw-Hill, NY, 1943
- (3) Naidich Y. V. Contact effects in metallic melts, Nauka, Kiev, Ukraine, 1972
- (4) Metcalfe A. G. Interfaces in metal matrix composites, Academic Press, NY, 1974
- (5) Jaycock M. J., Parfitt G. D. Chemistry of interfaces, Ellis Horwood Ltd., Chichester, UK, 1981
- (6) Seith W. Diffusion in metals, Springer Verlag, Berlin, 1955
- (7) Summ B. D., Gorunov U. V. Physical-chemistry of wetting and spreading, Chemie, Moscow, 1976
- (8) Mizutani U. Hume-Rothery Rules for Structurally Complex Alloy Phases, CRC Press, Boca Raton, 2011
- (9) Vianco P. T., Hosking F. M., Stephens J. J., Walker C. A., Neilsen M. K., Glass S. J., Monroe S. L. Aging of brazed joints-Interface reaction in base metal/filler metal couples, part 1, Welding Journal, 2002, vol. 81, #10, 201s-210s and Part 2, #11, 256s-264s
- (10) Dolgov Y. S., Sidokhin Y. F. Formation of the brazed joint, Machinostroenie, Moscow, 1973

- (11) Flom Y. Strength and margins of brazed joints, Chapter 2, in the book "Advances in Brazing", 2013, Woodhead Publishing, Cambridge, UK, pp. 31-54
- (12) Sekulic D. P. Modeling of the sequence of phenomena in brazing, Chapter 3, in the book "Advances in Brazing", 2013, Woodhead Publishing, Cambridge, UK, pp. 55-82
- (13) Zhao H. , Woods R. Controlled atmosphere brazing of aluminum, Chapter 10, in the book "Advances in Brazing", 2013, Woodhead Publishing, Cambridge, UK, pp. 280-322
- (14) Walker C. A. Metal-nonmetal brazing for electrical, packaging and structural applications, Chapter 16, in the book "Advances in Brazing", 2013, Woodhead Publishing, Cambridge, UK, pp. 498-524
- (15) Ditzel P. Thermodynamics for brazing, Lecture for WE4023, Columbus, OH, 2016-2019
- (16) Vianco P. T. Understanding the Reliability of Solder Joints Used in Advanced Structural and Electronics Applications: Part 1, Welding Journal, 2017, vol. 96, #2, 39s-52s and Part 2, #3, 83s-94s
- (17) Vianco P.T., Williams S., Kilgo A., Mckenzie B., Price W., Guerrero E. The mechanical performance of Sn-Pb solder joints on LTCC substrates, Welding Journal, 2019, vol. 98, #1, 1s-13s
- (18) Malkin A. I. Regularities and Mechanisms of the Rehbinder's Effect, Colloid Journal, 2012, vol. 74, No. 2, 239-256
- (19) Sekulic D. P. Brazing of aluminum alloys, Brazing Handbook, Chapter 1, vol. 3, AWS, Miami, 2020
- (20) Shapiro A. E. Brazing of conventional titanium alloys, ASM Metal Handbook, 6th edition, 2017, vol.6, 1-25
- (21) Shapiro A. E. Brazing of Graphite and Carbon Composites, Chapter 21, Brazing Handbook, 2007, pp. 381-407
- (22) Rabinkin A., Shapiro A. E., Boretius M. Brazing of superhard materials: Diamond and Boron nitride, Chapter 6, in the book Advances in Brazing, 2013, Woodhead Publishing, Cambridge, UK, pp. 160-193
- (23) Salvo M., Casalegno V., Rizzo S., Smeagetto F., Ventrella A., Ferraris M. Glasses and glass-ceramics as brazing materials for high-temperature applications, Chapter 17, in the book "Advances in Brazing", 2013, Woodhead Publishing, Cambridge, UK, pp. 525-544
- (24) Rabinkin A., Pounds S. Effect of load on brazing with Metglas MBF-2005 filler metal, Welding Journal, 1998, #5, 33-45
- (25) Coecke B., Kissinger A. Picturing quantum processes, Cambridge University Press, UK, 2017

Schedule and Assigned Reading (**Friday afternoon in EJTC 111**) 02-17-19 version

Date	Hrs	Topic	Reading
Block 1		Fundamentals of Brazing and Soldering	
01/10	3	Theory of wetting of solid metals. Structure and properties of metallic solid surfaces. Physical-chemistry of liquid-solid interface. Interfacial reactions in brazing and soldering. Thermodynamic aspects.	Textbooks: 3, 4 Reference texts: 1,2,4,5,12,15
01/17	3	Structure and properties of ceramic solid surfaces. Reactive wetting of ceramics by liquid metals and interfacial reactions. Formation of solid solutions, eutectics, and intermetallics in the joint metals and at the interface. Hume-Rothery rules and designing of brazing alloys.	Textbooks: 4 Reference texts: 4,5,8,9,14
01/24	3	Practical case studies of reactive and non-reactive wetting in brazing and soldering. Brazing of superhard materials: silicon carbide, aluminum nitride, diamonds, and boron nitrides.	Textbooks: 1, 2, 4 Reference texts: 21,22
01/31	3	Diffusion in brazing and soldering: theory, kinetics, effect on microstructure and mechanical properties of brazed joints. Diffusion exchange between solid and liquid metals. Matano diagram.	Textbooks: 3 Reference texts: 1,2,6
02/07	3	TLP process (diffusion brazing). Solidification of joint metal above solidus of the filler metal. Applications and control of brazing process. Diffusion brazing of titanium and nickel superalloys. Practical case studies.	Textbooks: 1,3 Reference texts: 1,2,6,13,20
02/14	1	Midterm exam	

02/14	2	Erosion and dissolution of base metals in the liquid filler metals. Liquid embrittlement of base metals during brazing.	Textbooks: 3 Reference texts: 1,2,18,19
Block 2		Strength and reliability of brazed or soldered joints	
02/21	3	Strength of brazed and soldered joints: a model of multilayer composite material, 3D-stresses, failure criteria to analyze brazed or soldered joints. Field tests against FEM modeling. Practical case studies.	Textbooks: 1,2 Reference texts: 11,12,16,17,24
02/28	3	Evaluation of joint's reliability by margins of safety approach. Methods of mechanical testing. Classification of defects in brazed or soldered joints. Ductile or brittle modes of mechanical behavior of brazed joints.	Textbooks: 1,2 Reference texts: 11,12,16,17,20,24
03/06	3	Lab Work: Mechanical testing of brazed and soldered joints: Standard lap specimens against express-tests (coupon-plug specimens). Bending test. Approximate measurement of yield strength of brazed joints.	Lab Work Manual
		Lab Report to April 9, 2020	
03/13		Spring vacation	
03/20	3	Hot strength, creep resistance, and fatigue of brazed and soldered joints. Fracture surface types of brazed and soldered joints. Practical case studies.	Reference texts: 1,9,11,16,17
Block 3		Brazing of advanced materials	
03/27	3	Brazing and soldering of dissimilar materials. Temperature dependence of partial pressure of different metals. Selection of filler metals and methods for heating. Practical case studies.	Textbooks: 1,2 Reference texts: 11,12,16,17,24
04/03	3	Advanced soldering: methods and materials. Reliability of soldered joints. Practical case studies.	Textbooks: 2 Reference texts: 9,14,16,17
04/10	3	Brazing of refractory materials: Mo, Ta, Nb metals, carbon composites, and ceramics. Practical case studies.	Textbooks: 1 Reference texts: 1,6,14
04/17	3	Brazing of glasses and glass-ceramics in optical and electronic applications. Practical case studies. New advanced materials for brazing: flux-cored aluminum filler metals, composite filler metals, high-entropy alloys, amorphous foils, and others.	Reference texts: 1,4,19,20,23
04/26	2	Final exam	
		Total: in class 44 hours, one Labwork 3 hours, 14 weeks 3 credits	