Meeting the Demand for Welding Engineers

Graduating highly qualified, well-prepared engineers and growing its research activities are primary missions of the Welding Engineering Program at The Ohio State University

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Welding engineering at The Ohio State University (OSU) traces its roots back to the 1930s. Over the ensuing 80 years, it has evolved into an academic/research program that is recognized throughout the world. The university currently has the only Accreditation Board for Engineering and Technology (ABET) approved engineering program in the United States offering a bachelor of science degree in welding engineering. Masters and doctorate degrees in welding engineering are also offered. The program has changed significantly over the past ten years with new faculty hires, a merger with the Materials Science and Engineering Department, growth in research activities, and the offering of online courses. In addition, unprecedented growth of the undergraduate student population is anticipated starting this year. This article provides a brief history of the program and an update on its current status and future direction.

A Brief History

In the years following World War I, arc welding became recognized as a viable technique for joining and repairing iron and steel. This led to increased interest in welding throughout the world. A small group of faculty in OSU's Industrial Engineering Dept. began promoting welding as a manufacturing technique, which eventually led to the organization of six welding conferences held annually from 1932 to 1937. This, in turn, resulted in the development of a combined Industrial/Welding Engineering degree program that was launched in 1938. Be-

Fig. 1 — Students learning to weld in 1958.

Fig. 2 — Professor McCauley delivering a welding metallurgy lecture, circa 1968.

tween 1938 and 1944, 20 BS Industrial Engineering/Welding Engineering degrees were granted, but the program was interrupted by World War II. The faculty supporting this activity were located in the Industrial Engineering building, which eventually became the home of the Welding Engineering Department.

In 1947, Robert S. Green was hired to establish a Welding Engineering Dept., which was formally launched on January 1, 1948. The curriculum that Green put in place included courses in metallurgy, mechanics and strength of materials, machine design, structural design, and electrical engineering. These core areas would form the basis of the multidisciplinary curriculum that exists today. The curriculum also included a hands-on component that allowed students to gain an appreciation of welding by learning the manual skills required — Fig. 1. The first class of welding engineers graduated in 1948. Through the 1950s and 1960s, Welding Engineering Dept. faculty averaged about three, and the department was heavily dependent on courses taught by other engineering departments. The MS degree in welding engineering was approved in 1956.

The late 1970s and early 1980s saw a dramatic increase in faculty led by Department Chairs Roy McCauley (Fig. 2) (1954–1979) and Karl Graff (1979–1987). This reduced the dependence of the welding engineering curriculum on courses from other departments and allowed expansion into the areas of nondestructive evaluation, robotics, and polymer joining. The increase in faculty also allowed development of a PhD degree, which was approved in 1985. In 1979, the National Science Foundation (NSF) awarded the department one of the first Industry/University Cooperative Research Center (I/UCRC) initiatives, resulting in a boost in research activity and an increase in graduate students. Total faculty in the department grew to ten — the highest level in its history.

In 1994, the department received another large NSF grant to build a comprehensive education and training program known as National Excellence in Materials Joining Education and Training. Through this program, more than 10,000 pages of slides and notes were created representing the largest single collection of teaching material

Fig. 3 — The Edison Joining Technology Center on OSU's west campus.

dedicated to materials joining. This material has since been used in courses at OSU and other universities, and to support continuing education and training programs, and formed the foundation of an online distance education program initiated in 2003.

In 1995, the Welding Engineering and Industrial and Systems Engineering departments were merged into a new department — Industrial, Welding, and Systems Engineering — in an effort to consolidate much of the university's manufacturing expertise into a single department. Shortly afterward, the welding engineering faculty moved to a new laboratory facility on OSU's west campus — Fig. 3. This facility, known as the Edison Joining Technology Center, colocated the welding engineering program with Edison Welding Institute (EWI). This created the largest welding/joining education and research facility in the western hemisphere with approximately 135,000 sq ft of space and more than 300 personnel (including students). The welding engineering program occupies approximately 35,000 sq ft, including modern laboratories, a student computer laboratory, faculty and graduate student offices, and training facilities.

The period from 2005 to 2010 saw the retirement of many of the faculty hired in the 1970s and 1980s including Dick Richardson, Charles Albright, Dave Dickinson, and Chon Tsai. To manage through this period of change, a transition planning committee was formed in 2008 led by former chair Karl Graff. The plan that evolved outlined a bold strategy for growth of the research program that would, in turn, support hiring of new faculty. In 2010, NSF awarded OSU another I/UCRC titled Center for Integrative Materials Joining Science for Energy Applications.

Currently, the eight welding engineering faculty (Table 1, Fig. 4) bring a diverse portfolio of expertise, experience, and national recognition in the field of welding engineering. Also, in 2010, the program moved from the

Fig. 4 — Welding engineering faculty and staff (from left): Mark Cooper, Ed Pfeifer, Heather Sever, Ken Copley, Dave Farson, Wei Zhang, David Phillips, Megan Daniels, John Lippold, Stan Rokhlin, Avi Benatar, Boian Alexandrov, and Menachem Kimchi.

newly named Integrated Systems Engineering Department and merged with the Materials Science and Engineering Department. This move had no effect on the welding engineering curriculum or degree programs, and has had a positive effect on the research program within welding engineering.

Academic Program and Students

The welding engineering program at Ohio State is often confused with an engineering technology program. As defined on the ABET website, "Engineering programs often focus on theory and conceptual design, while technology programs usually focus on application and implementation. Also, engineering programs typically require additional, higher level mathematics, including multiple semesters of calculus and calculus-based theoretical science courses. Engineering technology programs typically focus on algebra, trigonometry, applied calculus, and other courses that are more practical than theoretical in nature."

Welding engineering is a rigorous, complex engineering program that requires students to be proficient in a broad range of engineering disciplines. Prior to taking courses in welding engineering, students are required to take an engineering core that includes differential calculus, calculus-based physics, statistics, statics and mechanics of materials, and thermodynamics.

Upon being admitted to the program, students (Figs. 5–7) begin a curriculum (Table 2) that is the most interdisciplinary of any in the College of Engineering, including courses in materials science, mechanical, electrical, and industrial engineering. Within the welding engineering program, students take advanced courses in welding metallurgy that cover materials ranging from low-alloy and stainless steels to nonferrous alloys such as nickel, aluminum, and titanium to polymers. Welding process courses emphasize theory and fundamentals of all the important industrial welding processes including manual and mechanized arc welding, laser and electron beam welding, solid-state welding, and resistance welding.

Fig. 5 — Welding engineering students conducting Gleeble testing.

The students develop a thorough understanding of many electrical concepts in welding such as process control, and transformer theory and operation. Welding design courses cover the principles of important subjects such as computational modeling, heat flow, residual stress, fatigue and fracture, and weld design for various loading conditions using industry-standard codes such as AWS D1.1, *Structural Welding Code — Steel*, and ASME *Boiler and Pressure Vessel Code*. Nondestructive materials characterization techniques including X-ray, ultrasonics, eddy current, magnetic particle, and dye penetrant are emphasized. The fully equipped center provides students numerous opportunities to get hands-on experience through a variety of welding process laboratories, including arc (manual and mechanized), resistance, laser, and solid-state welding. All students are required to complete one summer engineering experience, and spend their

Table 1 — Welding Engineering Faculty at The Ohio State University

Faculty	Title	Area of Focus
Boian Alexandrov	Research Associate Professor	Welding metallurgy, weldability evaluation, phase transformation analysis
Avi Benatar	Associate Professor	Welding of polymers and adhesive bonding, welding design
Dave Farson	Associate Professor	Laser and arc welding processes
Menachem Kimchi	Lecturer	Resistance and solid-state welding processes
John Lippold	Professor	Stainless steel and nonferrous welding metallurgy, weldability testing
David Phillips	Associate Professor of Practice	Welding processes, welding metallurgy
Stan Rokhlin	Professor	Nondestructive materials characterization
Wei Zhang	Associate Professor	Modeling and stress analysis

entire senior year working on an actual "real-world" engineering project under the guidance of their industry sponsor.

The academic potential of incoming students entering Ohio State's College of Engineering continues to grow steadily — Fig. 8. Some indicators of that improvement are 1) in 2013 the average composite ACT score for Columbus campus engineering students admitted to Ohio State was 29.5 whereas in 2006 it was 27.6, and 2) 54% of all 2012 incoming freshman were ranked in the top 10% of their high school class, and 89% in the top 25%. This quality is reflected in the students currently in welding engineering.

Fig. 6 — A student conducts a delayed hydrogen cracking test.

Graduate Programs and Distance Education

The welding engineering graduate program has grown significantly in recent years with increased research funding and growth in distance education. In addition to the MS and PhD degrees offered, a fully online MS in welding engineering is available to qualified students. Like the undergraduate program, the graduate program is math and science based with emphasis on leading and advancing

Table 2 — Undergraduate Welding Engineering Curriculum (does not include general education requirements)

Year	Autumn Semester	Spring Semester
1	Fundamentals in Engineering I Calculus I Physics I	Fundamentals of Engineering II Engineering Mathematics I Chemistry for Engineers I
2	Introduction to Materials Science and Engineering Engineering Mathematics II Physics II Statistics for Engineers Statics and Mechanics	Differential Equations for Engineers Thermodynamics Survey of Welding Engineering Arc Welding Laboratory Electrical Circuits and Devices Computer Programming
3	Structural Transformations in Metals Materials Processing Laboratory Physical Principles in Welding Processes I (Arc Welding) Welding Engineering Design I	Physical Principles in Welding Processes II (Non-Arc Welding) Welding Metallurgy I Welding Metallurgy Laboratory I Welding Design II Nondestructive Evaluation Fundamentals of Manufacturing Engineering
4	Industrial Experience Welding Metallurgy II Welding Metallurgy Laboratory II Senior Design I	Senior Design II Engineering Economics
Technical Elective Courses	Resistance Welding Adhesive Bonding Weldability Novel and Hybrid Process Welding Computational Thermodynamics Weld Process Control	High Energy Density Welding Solid-State Welding Brazing and Soldering Welding of Plastics and Composites X-Ray and Ultrasonic NDE Robot Programming

materials joining education and research.

The MS can be completed with or without a thesis, and includes a depth and breadth requirement. For the depth requirement, students can choose a sequence of courses in one of the following areas: welding processes, metallurgy, design, nondestructive evaluation, and joining of plastics and composites. For the breadth requirement, they take one course (usually the first introductory course) in the remaining four areas that they have not selected for their specialization. In addition, they can typically take one or two technical electives that can be outside welding engineering. Most on-campus MS students select the thesis option, while nearly all distance students select the nonthesis option. However, even the nonthesis option includes a smaller culminating open-ended independent study project.

The PhD in welding engineering is usually pursued by students who already have or recently acquired an MS degree in welding engineering or another engineering discipline. With special approval by the Welding Engineering Graduate Studies Committee, exceptional students can proceed directly from a BS in engineering to the PhD program. The PhD program includes a sequence of courses specializing in one of the following areas: welding processes, metallurgy, design, nondestructive evaluation, and joining of plastics and composites. In addition, students select one of the remaining areas for a minor (fewer courses) and another minor outside welding engineering related to their research work. The PhD dissertation is an extensive body of research work that advances the knowledge in materials joining or allied field.

The online web-based MS in welding engineering was established in 2003 to expand the availability of a welding engineering education to a wider audience. Online courses were first offered in the 1998–99 academic years and have grown to the point where nearly all graduate courses are now available online. In addition, the faculty in the Materials Science and Engineering Dept. have added online course offerings specifically for welding engineering distance education students. The program is designed for engineering professionals who typically take one or two courses per semester, and complete the program in about three years.

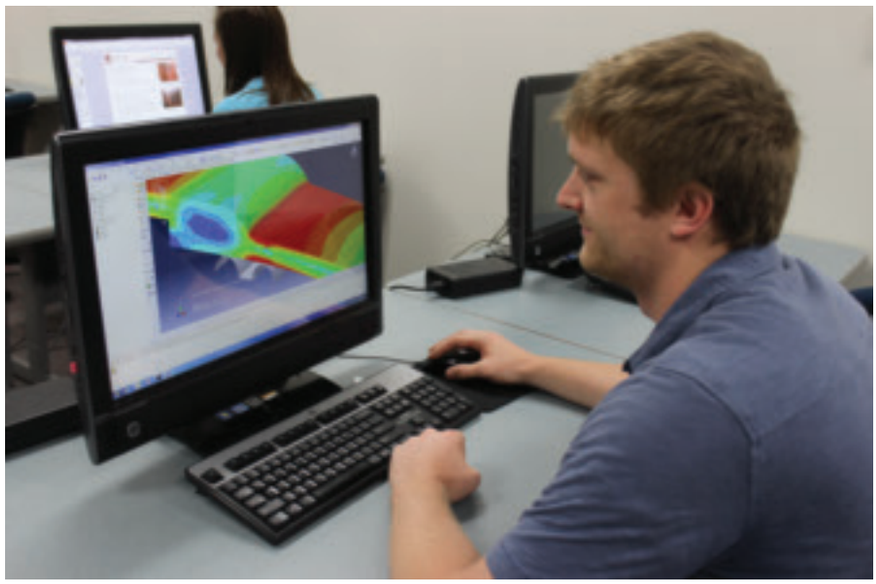

Fig. 7 — Modeling of stress on a weld test coupon.

As previously noted, enrollment in the welding engineering graduate programs has increased significantly in recent years. With increased research funding, on-campus enrollment is at about 35, split nearly evenly between MS and PhD students. With the change to semesters and reduced cost for online courses, enrollment of online MS students is at an all-time high with approximately 35 students actively enrolled in the MS program and 12 students exploring the program by taking courses as graduate nondegree students. While welding engineering is not ranked separately, the Materials Science and Engineering Dept. was ranked 18th in the most recent *U.S. News and World Report* Graduate School rankings. The College of Engineering, with the only online degree being the MS in welding engineering, was ranked 23rd in the most recent *U.S. News and World Report* Best Online Graduate Engineering Programs rankings.

Research Activities

Since the 1970s, research has been an important component of the program. Early faculty including Clarence

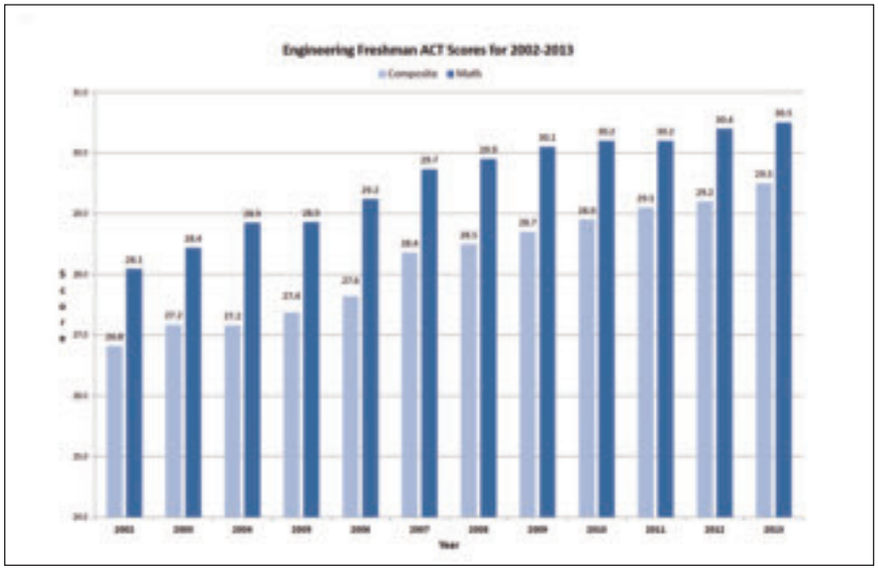

Fig. 8 — ACT scores of incoming Ohio State engineering students since 2002.

Jackson and Robert McMaster helped establish the university in the welding research arena and many were to follow. In the early years, research at Ohio State tended to focus on process technology, while programs at Rensselaer Polytechnic Institute and Lehigh University were known for metallurgy and mechanical behavior, respectively.

The establishment of the NSFI/UCRC in 1979 and the expansion of faculty in the late 1970s and early 1980s broadened and expanded welding research at Ohio State. While the welding process area remained a strong focus, there was significant growth in the areas of welding metallurgy and nondestructive evaluation.

The current research program within welding engineering encompasses a number of technical areas with welding metallurgy, weldability, and process modeling among the strongest of these programs. Annual funding for research performed by welding engineering faculty and staff is on the order of $2 million/year, supporting the approximately 35 on-campus graduate students.

The centerpiece of current research activities is the NSF I/UCRC for Integrative Materials Joining Science for Energy Applications. This center was established in 2010 in conjunction with Lehigh University, Colorado School of Mines, and the University of Wisconsin, with Ohio State serving as the lead organization. The I/UCRC concept uses NSF "seed funding" to develop a technology roadmap and attract organizations (industrial companies, national labs, research centers) who pay an annual membership fee. The members select the research topics and the results are shared among the member organizations.

Under the leadership of Dr. S. Suresh Babu, its first director, the center grew rapidly and reached 20 member organizations in the first two years. The center currently has more than 30 members and is one of the largest of the NSF I/UCRCs (70th percentile in number of members, 75th percentile in membership revenue). Total funding has exceeded $5 million, of which roughly 75% comes from the member organizations. It currently supports more than 25 graduate students and a number of postdocs at the four universities.

Research activities are grouped around five thrust areas: Materials Development, Joining Dissimilar Materials, Weldability and Life Extension, Integrated Process Modeling, and Innovative Process Control. A new thrust area in Additive Manufacturing is being launched this year.

In addition to the I/UCRC, considerable research is ongoing through a combination of federal and industrial funding. In particular, there are a number of research projects that support the power-generation and petrochemical industries. These include group-sponsored projects investigating failure mechanisms in welded tubing for coal-fired power plant applications, the use of cold metal transfer welding technology for cladding operations, and dissimilar joining of steels to stainless steels and Ni-based alloys. The Department of Energy, National Institute of Standards and Testing, and Electric Power Research Institute support other large programs. Total research funding in welding engineering at Ohio State is at the highest level in its history, and the average funding per faculty (~$400,000/year) is among the highest in the College of Engineering.

Welding Engineering Careers

The ABET website also provides some general insight regarding career paths for graduates of engineering programs vs. technology programs: "Graduates from engineering programs are called engineers. They often pursue entry-level work involving conceptual design or research and development. Many continue on to graduate level work in engineering. Graduates of four-year technology programs are called technologists, while graduates of two-year engineering technology programs are called technicians. These professions are most likely to enter positions in sectors such as construction, manufacturing, product design, testing, or technical services and sales. Those who pursue further study consider engineering, facilities management, or business administration."

The emphasis on fundamentals and engineering principles develops critical problem-solving and decision-making skills that graduates can utilize throughout their careers. The diverse curriculum prepares students for a wide range of possible careers. Over a recent five-year period, graduates have been hired by more than 50 different companies in industry sectors that include nuclear, petrochemical, automotive, medical, aerospace, power generation, and heavy equipment. In the 2012/2013 academic year, the average starting salary (approximately $64,000) for students with a BS in Welding Engineering was ranked highest in Ohio State's College of Engineering. The number of welding engineering jobs continues to be significantly greater than the supply of welding engineers.

The Future

The program is arguably at the strongest position in its history. The record number of undergraduate students (Table 3), a vibrant research portfolio, and a thriving distance education program are all indicators of the current strength of the program. The program is internationally recognized in the field of materials joining and has achieved the stature of other successful programs, such as those at Harbin Institute of Technology in China, Osaka University in Japan, and Aachen University in Germany.

The NSF I/UCRC continues to expand. Membership is expected to grow to more than 40 companies by 2015 and new initiatives in manufacturing

Table 3 — Recent Undergraduate Enrollment in The Ohio State University's Welding Engineering Program

	2009	2010	2011	2012	2013	2014
WeldEng PreMajors	35	26	45	49	74	86
WeldEng Majors	60	47	47	51	69	105
WeldEng Total	95	73	92	100	143	191

will greatly expand the center's research base. It enters Phase II in 2015, which guarantees NSF support for an additional five years. On its current path, this center will eventually become the platform to obtain larger federal and industrial grants focused on materials joining and manufacturing.

At the college level, there has been a renewed interest in manufacturing. Ohio State's competitive advantage in the manufacturing research arena comes, in part, from its unique strength in materials joining. The university, in partnership with EWI and the University of Michigan, recently won a competition to establish a new center as part of the National Network for Manufacturing Innovation. This center, the American Lightweight Materials Manufacturing Innovation Institute, will support projects that strive to introduce more lightweight materials into the transportation industries. Materials joining has been identified as one of the key enabling technologies in this endeavor. It is anticipated that this center will help foster closer collaboration between Ohio State's welding engineering program and EWI.

The mission of the program moving forward will be to continue to graduate highly qualified welding engineers who are well prepared for a wide range of engineering challenges. With the extreme demand for welding engineers combined with growth in both student enrollment and research funding, the future of the program appears strong. But whereas the uniqueness of the program offers obvious advantages, it's important to point out that this attribute has the potential to weaken its stability as those outside the program often ask, "What is Welding Engineering?" or "Why Welding Engineering?" In this regard, the ongoing support of both alumni and organizations who hire Ohio State welding engineers will be critical to the continued success of the program. WJ

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