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Teaching Introduction to Welding in Undergraduate and Graduate Engineering Technology Programs

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Dr. Eisazadeh joined Old Dominion University (ODU) in Fall 2018. Before joining ODU, he was a faculty member at the County College of Morris for one year, and a faculty member at the Chabahar Maritime University over four years. Dr. Eisazadeh received his Ph.D. (2017) in Mechanical Engineering from Clarkson University in New York, his MSc (2005) in Manufacturing Engineering from Tehran University, and his BS in Manufacturing Engineering from Mazandaran University. He has several years of research and teaching experience, and he is a member of American Welding Society.

His work involves studying residual stress formation in dissimilar weld and additive manufacturing using finite element modeling and neutron diffraction measurement. He has examined and practiced various modern techniques to mitigate weld residual stresses and their consequences. Through his work, he has presented at several conferences and co-authored papers on the reduction of residual stress in dissimilar weld.

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Teaching Introduction to Welding in Engineering Technology Programs

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Abstract

Recent trends in the industry have led to an increased need for engineers with welding training. Not many universities in the U.S.A. offer welding courses at undergraduate level. Engineers that do not receive education about this complex process, sometimes they make a very costly and dangerous mistake. More profound understanding of the welding process that expands beyond the basic comprehension of technology use is needed for the advanced manufacturing sector. Welding related courses, as it involves the complex interplay of the four states of matter (solid, liquid, gas and plasma) as governed by the laws of physics, need topics such as material science, phase diagrams, phase transformation, heat treatment, and possible failure modes of welds and working with special alloys and material that are difficult to weld. This paper will present two such courses at two different universities, both offered in mechanical engineering technology programs. These courses cover various welding processes, heat flow, residual stress, design, problems, codes, standards, and most importantly metallography.

Introduction

Some welding training programs embed the use of virtual reality application for the purpose of simulating the welding process in a safe environment and with fewer resources needed than the real welding laboratory [1]. Industry training systems in welding also use virtual reality for training of their workforce in virtual environments in which trainers and students can interact and troubleshoot possible problems that can happen during the manufacturing process such as in engine assembly and car body assembly [2]. Some facilities offer collaborative approach to use and maintenance of welding facilities [3].

Research has shown that being male and having agricultural mechanical courses in both high school and college were positively associated with having competency in welding and small gasoline engines, while having only a Bachelor's degree was negatively associated with having competency in welding and small gasoline engines [8]. Many undergraduate students in engineering and engineering technology programs did not come for Career and Technical Education (CTE) programs and often welding career pathway which is available under CTE programs in many regions is disconnected from engineering technology and engineering career pathway. Somehow that link in between the making part of engineering and engineering technology was broken after there was a trend to shift engineering programs more towards engineering science, and engineering technology program more to teaching computer integrated manufacturing, product lifecycle management, Internet of Things, Industry 4.0. etc. The need for these two kinds of programing have been added to multiple engineering and engineering technology programs and some of the core "making" courses such as welding were lost due to a limited number of credits, and probably higher cost of maintenance and high cost of that kinds of hands-on instruction. Classroom with computers only might be cheaper to maintain than the full lab needed for successful welding program.

Welding Career Pathway

Various vocational technical education schools offer welding training to students through the training that include introduction to welding and detecting welding defects [4]. Welding training in higher vocational schools has to focus on professional skills and certificates that are accepted by industry [5]. Some suggest that welding learning process have to include interaction of students and their teacher and that it has to include the following: a) the melt (the most central aspect); b) metal transfer mode (weight drop and how the melt flows in relation to welding mode, as here, position B); c) the base material; d) the arc length; e) the movement; e) travel speed; f) the body position; g) the current (amperage); e) the distance to the welding material; and f) the base material [6]. It is also important to define the ways that student and a trainer will interact [6]. Hands on welding happens in the environment with different visual and audio observations and it is different how student and teacher can interact. It is important to observe and analyze these teacher-student interactions and understand which practices yield the most successful learning results [7].

Some training programs offer two-year certification programs in welding that is based on curriculum from American Welding Society (AWS). Some of the topics that such program can include are Safety; Structural Welding; Oxygen/acetylene welding; Oxygen/acetylene cutting; MIG and TIG welding; Basic Rod Identification and Us; Blueprint reading/Layout and Design; Electrode selection; Joint design; Metallurgy; Quality Control; Symbols; Technology [9].

The course Introduction to Welding Technologies is offered at University A (blind-review) starting in Fall 2014. This course prepares Mechanical Engineering Technology (MET) students for professional careers in a wide range of local welding industries including shipbuilding, heavy equipment, automotive, aerospace, industrial equipment, material handling, welding equipment, etc. They are trained to be involved in a variety of activities such as design, inspection, quality, problem-solving, improving manufacturing efficiencies by choosing the best welding process and material and etc. This course uses both class lecture and hands-on approaches. Students learn the science and language of welding and engineering so that they will be able to span the gap between design and manufacturing at the undergraduate level. Some of the topics that are covered in this courses are: fusion and solid-state welding processes, physics of welding, welding design, welding symbols, heat flow in welding, residual stress and distortion, mechanical properties of welded joints, weld defects and discontinuities, welding codes, qualification, and certification, inspection and NDE, basic metallurgy and welding metallurgy.

Example of the Welding Course in Engineering Technology Undergraduate Education

It is important that students are exposed to various welding machines and learn the basic knowledge of welding technique through hands-on experience. Since University A does not have a welding lab yet, collaboration with a local community college was established where there is a welding space for training for a college student. In Fall 2018, a collaboration was established temporally between ABC Community College (blind-review) and University A to provide students with an opportunity to use various welding machines, including GMAW, GTAW, SMAW, and FCAW processes. In two convective sessions, the undergraduate students learned the basic welding process and enjoyed this training experience. In the student evaluation reports, students reflected that these sessions were invaluable for them and they wish that they had many more these training sessions. As such, Old Dominion University is now working to set up an in-house welding lab for Fall 2019 so that student will be provided more welding training session on campus. Therefore, traveling to off-campus locations for students which cost time and money will be avoided.

Project

The undergraduate students at ODU are also exposed to learn metallography of welds through experiment. At the beginning of the semester, all students are provided with a project outline and detailed steps. This project normally lasts at least 8 weeks. The main objective of this project is that students learn how to analyze the weld by examining the microstructure of welds. They are trained to produce professional micrographs through various polishing steps and etching. They become skilled to take quality macro and micrographs of weld cross sections. More importantly, they will be practiced to take micro hardness reading on the weld surface and weld boundaries. The project steps are summarized as follows:

1- Project assigning
2- Create welds
3- Cut specimens and bend tests
4- Mount specimens
5- Polish specimens
6- Etch specimens
7- Image specimens
8- Hardness test specimens

1. *Project assigning*

In this step, students are arranged to form groups of maximum two people. Each group will be provided six similar metal plates that they need to join them using GMAW, GTAW, SMAW processes. This provides students with an excellent opportunity to compare microstructure of three welding processes. This step requires one week for cutting the plate in size.

2. *Create welds*

Students are instructed to perform GMAW, GTAW, SMAW welding processes. They are given safety instruction and practical hints for holding welding torches to create acceptable welds. Figure 2 shows a student with proper clothing is practicing the GMAW process.

Figure 1: Student performing MIG welding process

Figure 2 shows a typical weld practice made by a student.

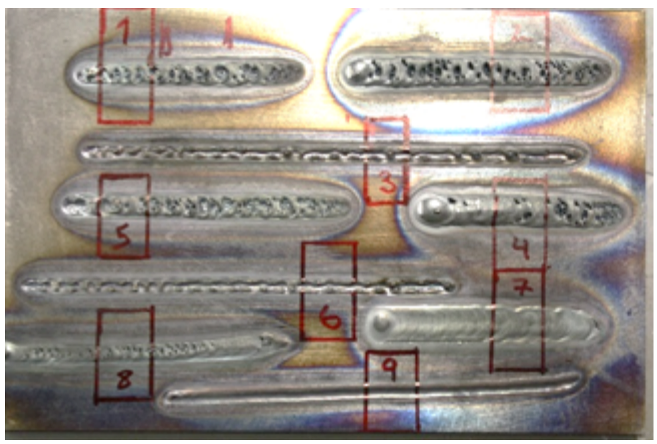

Figure 2: A typical student weld practices

3. *Cut specimens and bend test*

Once students make a quality weld, they are taught to cut specimens out of their weldments. Students need to make sure that they use appropriate labels on their specimens so that they can distinguish their specimens later on. Figure 2 demonstrates 9 regions on a weld practice that can be was used for metallography and bend test.

Students are required to conduct bend test on their specimens because it is one of the quality control tests for welded joints. This test is simple and inexpensive. The test specimen is are easily prepared and little instruction is needed for students to carry out the bend test on the shop floor. Figure 2 displays a three-point bend test for weld specimens.

Figure 3: A typical bend test

4. *Specimen mounting*

To polish the specimens effectively, it is recommended to mount the weld specimens in epoxy. An easy to follow instruction is provided to students to mix epoxy with hardener and place the specimens in the cup correctly so the specimen located in desired arrangement for the following steps such as polishing and micrograph photos. Figure 5 shows three specimens at different steps of mounting.

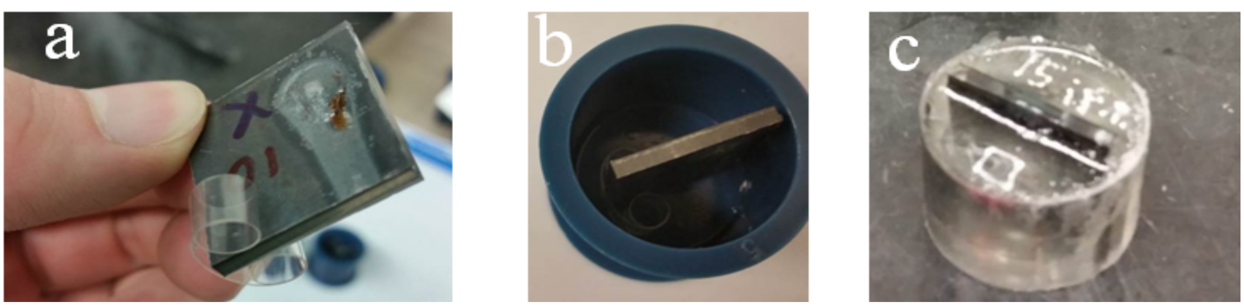

Figure 4: Specimen is mounted in epoxy, a: a holder is used to keep the sample upward, b: specimen is placed in the cup and epoxy is poured into the cup, c: after 24 hours epoxy becomes dry and is ready for polishing.

5. *Specimen polishing*

This step sometimes becomes tedious for students as it requires repetition of polishing from coarse grit to fine grit. They are required to use 320, 400, 600, 800, 1200 silicon carbide papers in order to create a smooth and shiny metal surface. after this sequence, they use very fine 3 μm and 1 μm diamond grit. Figure 5 shows a typical arrangement of the specimen in an automatic polisher machine.

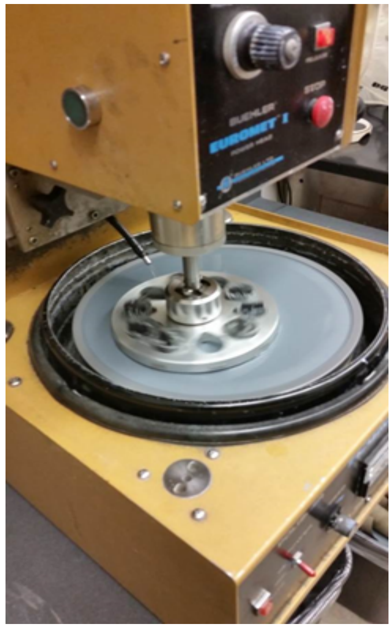

Figure 5: An automatic polisher for polishing weld specimens

6. *Etch specimens*

In this stage, students learn the most common etchant for steels and how to mix them in the hood and use them outside hood safely. They are introduced various techniques of applying to each such as immersion and swab etching and electrochemical etching. They are introduced to these three general etchants, 2% nital for carbon steel, glyerigea, and aqua regia etch for nickel and stainless steel and salt mixture etch for aluminum. A typical swapping procedure for etching specimen is shown in Figure 7.

7. *Image*

Student use both inverted and stereo microscopes to capture quality macro and micrograph photos from the specimen. They are taught that various part weld specimen exhibit various microstructure and grain size because of the different cooling rate. In this step, they learn important parts of the microscope to acquire best micrographs including illumination, contrast, brightness, focus and scale bar. In addition, students are warned that they should obtain micrographs as many as they require at this step before moving to the next step because hardness measurement leaves indentation spots on the specimen surface.

8. *Hardness Testing*

The last step is the Vickers hardness test that students are provided with instruction on how to use the indentation tester machine. As there is the relation between microstructure and hardens, this step is of crucial step that student must be trained to interpret hardness results and related them to the microstructure of the specimen. Figure 7 shows a student measuring with micro hardness tester machine.

After all these processes, students are asked to write a report and talk about their observation for this project. A typical micrograph of weld specimen taken by a group of students at ODU is shown in Figure 6.

Figure 6: A typical swapping procedure for etching specimen

Figure 7: A student using micro hardness tester machine

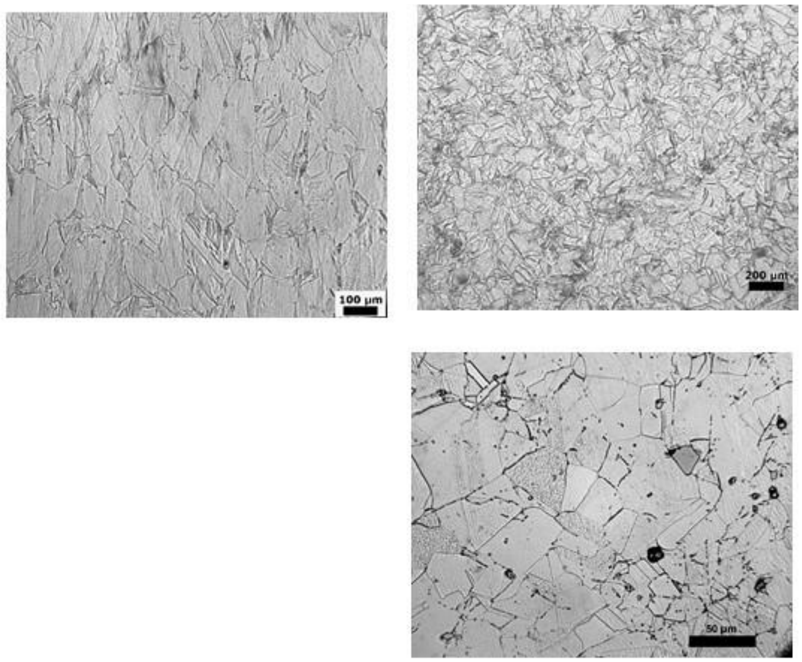

Figure 8 Micrographs of Nickel Alloys prepared by a group of students at ODU

Example of the Welding Course in Engineering Technology Graduate Education

At University B (blind-review), there are no undergraduate courses concentrated on welding only. Instead, welding is taught as part of manufacturing courses. In the Engineering Technology program, welding is introduced to undergraduate students in Materials and Processes I, which covers basics of materials science, metal forming, metal casting, and welding. Recently, a graduate-level welding course, Welding Technology for Manufacturing and Agriculture, was developed and offered by the School of Engineering Technology. The course is cross-listed with the course of Welding Engineering to serve students in the Agricultural and Biological Engineering (ABE) program. Despite being a graduate course, about half of the enrolled students are undergraduates from the ABE program in their senior year. In that sense, this course serves undergraduate education in welding.

Being a graduate-level course, its emphasis is on in-depth theoretical analysis of physical and chemical phenomena that occur in welding. In the same time, for most students, this is their first course in welding, which requires a broad scope of topics. For that reason, depth has to be sacrificed for breadth. The following is a list of topics tailored for three-hour long blocks:

- Safety in welding. Basic principles of welding, brazing, and soldering, and their differences. Survey of welding processes. Welding symbols.
- Heat transfer in welding.
- Theory of nucleation and solidification.
- Theory of rapid solidification. Microstructure development in welding.
- Development of residual stresses in welds. The strength of welds.
- Defects in welds. Inspection and testing of welds. Weldability tests.
- Analysis of best practices in SMAW, GMAW, and GTAW processes. Models of melting rates in those processes.
- Weldability of steels. Weldability of irons.

- Weldability of aluminum and its alloys. Weldability of titanium and its alloys.
- Weldability of other materials (superalloys, copper alloys, magnesium). Brief remarks on monitoring of welding processes.

The most important topics are those that cover heat transfer, solidification, and stresses in welds. They are building blocks repeated throughout the rest of the course to explain origins of various defects and method of their prevention, to justify basic principles of weldment design, as well as to explain weldability of various materials and why certain measures are needed in order to make their welding possible. This list of topics is obviously so broad that it calls for at least three courses in order to give them enough attention.

Students are recommended a few monographs, as well as a set of the AWS Welding Handbook, but none of them is required to successfully complete the course. Instead, over one hundred and fifty scientific and technical papers are posted on the University B (Blind-review)'s learning management system. Papers in each section are milestone works in that discipline and span a few decades of development of theory and practice. Each week students are assigned to read on average two to three papers that will be referred the most during the next lecture.

Even though theoretical in nature, practice, and observation is a very important component of this course. The equivalent of laboratory exercises in undergraduate classes, the purpose of practice and observation is to perform simple experiments in order to verify theoretical calculations and point out their limitations and some trends. The course is offered as 3 lecture hours per week and no laboratory hours, which is traditional for graduate courses. However, the class meets once a week in a single block of 3 hours, allowing enough time for experimental work. There are four blocks of experimental work scheduled, and they cover the following experiments:

- During the first practice/observation work, students make bead-on-plate and single-square-groove welds on 1018 steel using autogenous GTAW while timing the weld. Welds shall be far enough to avoid overlapped heat affected zones. After the samples cool down, they measure the bead width. Some samples are cross-sectioned, polished, and etched in order to reveal the shapes of the weld pool and heat affected zone. The findings are compared with approximate theoretical calculations.
- During the second experimental period, students perform SMAW, GMAW, and GTAW with added filler material. The base material is 1018 steel. They measure the sample weight before and after welding, as well as measure time to make the weld, which gives the melting rate of the filler material. Those melting rates are compared with theoretical calculations for SMAW and GMAW. Students also see how filler material affects the shape of the weld pool and heat affected zone.
- The third laboratory period focuses on the soundness of welds. They make multi-pass single-V-groove welds using SMAW and GMAW methods. SMAW is performed with and without grinding the root pass. The weld soundness is tested with a guided bend testing method, performing face and root bends. Students have the opportunity to compare efficiencies between SMAW and GMAW and how much cleaning slag between passes influence welding efficiency and quality of welds.
- The fourth exercise will be introduced for the first time this semester. It will give students the opportunity to weld stainless steel and aluminum and compare that experience with welding 1018 steel. They will also learn to appreciate the importance of adhering to recommendations in order to successfully weld these materials.

The welding laboratory at University B’s School of Engineering Technology has one instructor’s station with GTAW/SMAW and GMAW welding machines, and eight booths with GTAW/SMAW welders, at this point equipped for SMAW only. The above-mentioned experiments are not time-consuming, so while one group of students is working on the experiment, others are welding on their own in one of eight welding booths and experiment with different welding positions and shielded electrodes.

It should be noted that welding skills are irrelevant in this course, and participation in welding experiments is not mandatory. However, no student so far opted out of participation in welding practices. Moreover, the students comment that these exercises help retention of theoretical knowledge and make them appreciate the complexity of the welding process. For example, they experience first-hand that weaving the electrode, Figure 9, increases the heat input. Heat input, in turn, dictates the weld penetration, Figure 10.

Figure 9: Two 1018 steel samples bead-on-plate and single-square groove autogenous GTAW welds. Left: weaved beads. Right: stringer beads with signs of an unsteady hand.

Students also observe that the temperature isotherms are indeed close to semi-circular shape in case of a thick plate and when no filler material is added, as illustrated in Figure 11. Students also witness that theoretical models make sense and show correct trends, even when compared with their maiden welds with a lot of unsteadiness. Figures 10 and 11 show that the weld size depends on the travel speed and that the same sample can behave like a thick or thin plate, or in between, depending on the heat input.

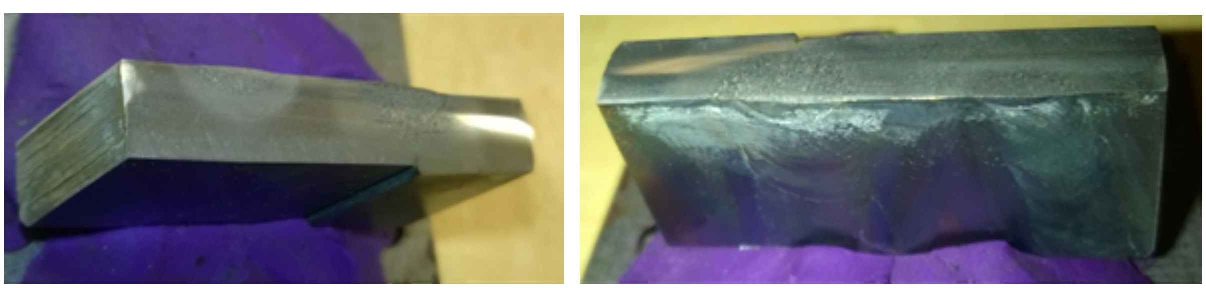

Figure 10: Cross-section of bead-on-plate and single-square groove welds on 1018 steel made with autogenous GTAW. Semi-circular weld bead and heat affected zone are visible.

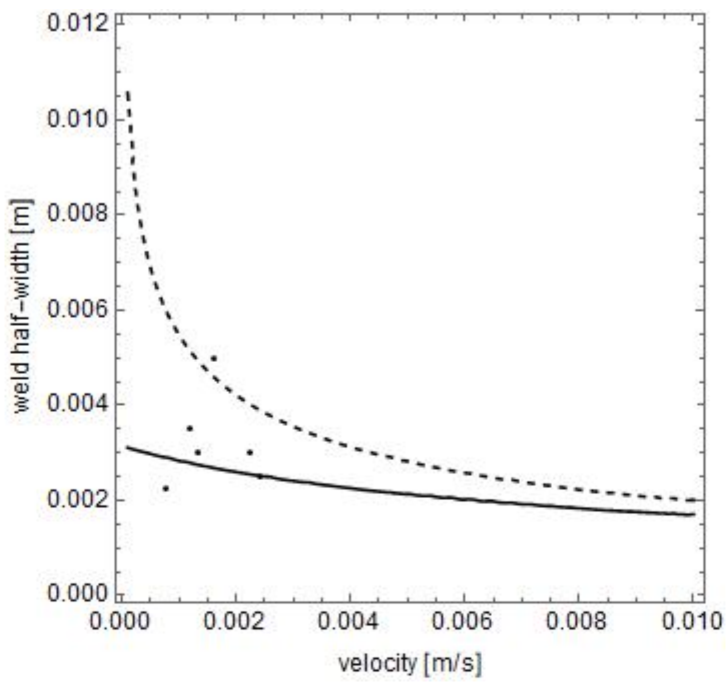

Figure 11: Theoretical curves for thin-plate approximation (dashed line) and thick-plate approximation (solid line). Dots are measurements of the successfully welded sample. The sample with weaved bead in Figure 10 is represented with a dot closest to the dashed line.

Students shall be given the opportunity to appreciate the practical side of good welding practices. For example, students are tasked to make multi-pass, single-V-groove welds with and without grinding the root pass to expose clean weld, before continuing with subsequent passes. In all the cases the weld cracked during the bend test, Figures 13 and 14. The importance of proper arc termination is also stressed, and why run-off tabs are required in some applications. They also learn to appreciate the time needed to clean slag between passes when doing SMAW, and efficiency of the GMAW process.

Figure 12. A guided bend test of welds.

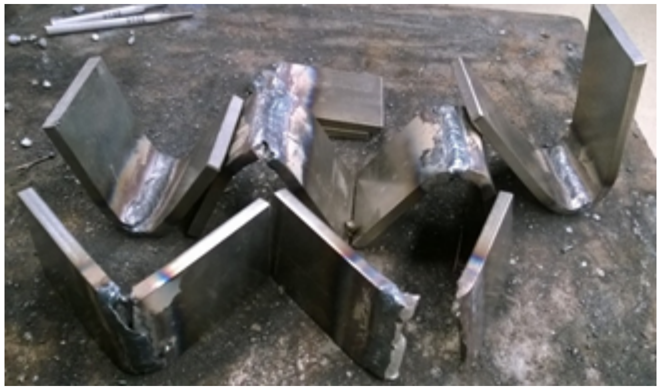

Figure 13. Some of SMAW welds after the bend test. It is easy to guess which samples were welded without grinding of the root pass to remove slag. Two samples also show effects of craters and slag inclusions created during arc termination.

The assessment in Welding Technology for Manufacturing and Agriculture/Welding Engineering consists of five homework assignments, two exams, and one seminar work. Results from experimental work in the laboratory are included as part of homework assignments and compared with theoretical calculations with reflection on trends observed. It should be noted that the agreement between experiments and theory is not required, but what matters is insight in explaining the differences. Exams are problem-based, open-ended, and students are given 24 hours to complete it. Seminar work includes an in-depth analysis of a topic of their choice, which concludes with the written report and informal presentation with open discussion during the last class meeting.

Conclusion

Since the industry is lacking people with advanced welding knowledge at the engineering and engineering technology level, there is a need for more courses that are focused on an in-depth overview of material science and engineering behind the welding. Welding is a complex process that combines together various disciplines, and it would be the most optimal to cover them in several courses. In introductory survey courses, whether at the undergraduate or graduate level, it is very important to strike the right balance between breadth and depth of the topics covered. The significance of practical experiments has been demonstrated to increase an acceptance of theory and retention of knowledge. However, an appropriate amount of practical work is also important because the focus of college courses is not to develop manual welding skills, but an appreciation of its complexity and the purpose of the topics presented throughout the course. These topics are especially important for advanced manufacturing processes, various industries that will have welding for sure no matter how advanced technology changes.

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