WLD 221
Gas Tungsten Arc Welding
Mild Steel

NSF	This project was supported, in part, By the **National Science Foundation** Opinions expressed are those of the authors And not necessarily those of the Foundation

Course Assignments

Required text book and Reading

Welding Principles and Applications, By Larry Jeffus

Gas Tungsten arc Welding Equipment, Setup, Operation and Filler Metals

Gas Tungsten Arc Welding of Plate

Video Training

Hobart Instructional Videos on the PCC Library site

Writing Work Sheets

Power Sources
Welding Torch
Tungsten Electrodes
Shielding Gas

Welding Projects

Flat Position	Horizontal Position	Vertical Position	Overhead Position
Edge Joint	T-Joint	T-Joint	T-Joint
Corner Joint	Lap Joint	Lap Joint	Lap Joint
Bead Plate	Corner Joint	Corner Joint	Butt Joint
T-Joint	Butt Joint	Butt Joint	

Final Exam

Part One (Closed Book Exam)
Part Two (Practical Exam)

Science on Steel

Contents of this Packet include

- Weld Cleanliness
- Electron Emission by Tungsten Electrode
- Use of Thoriated and Ceriated Electrodes
- Cleaning Action
- Surface Tension Driven Flow of Weld Metal affecting Penetration

Weld Cleanliness

Compared to SMAW, FCAW and GMAW, weld metal deposited by GTAW properly will be free of contamination of any kind. GTAW is a hydrogen-free process. The tungsten electrode and the molten metal pool are free of contamination because of the argon shielding gas used in welding. The only source of contamination is due to lack of good workmanship. Although GTAW is a very clean process, it can produce porous welds because of poor workmanship. For example, if the work-piece is covered with oil, grease or paint, the weld metal will contain porosity and be susceptible to hydrogen-assisted cracking.

Electron Emission by Tungsten Electrode

The temperature of the central core of the arc in GTAW can approach approximately 30,000ºC (54,000º F). The presence of metal vapors from the filler metal and even the tungsten electrode itself will reduce the arc temperature slightly. The actual temperature of the arc during welding is limited by several sources of heat loss, namely;

- Radiation
- Convection
- Conduction and
- Diffusion

Radiation from an arc varies from long wavelength infrared radiation to visible to short wavelength ultraviolet light. As intense as the gas tungsten arc is, the energy of the radiation is not high enough to produce x-rays, (which is abundantly generated in electron beam welding). The energy of radiation (E_{rad}) is a function of the wavelength (w), as shown below:

$$E_{rad} = h/w$$ where h is Plank's constant

The amount of arc radiation taking place during welding increases with arc temperature and atomic mass (of the media carrying the arc such as argon or helium). Using argon with GTAW, losses of up to 20% of the heat input are possible. Since the gas tungsten arc contains such intense ultraviolet energy, the problem to skin damage (similar to severe sunburns) takes place rapidly. Compared to GMAW, FCAW and SMAW, the GTAW process can cause the most severe skin burns if poor protective clothing is used.

Use of Thoriated and Ceriated Electrodes

In DC operation, pure tungsten electrodes are not used because the tip of the electrode melts and the cathode spot moves unstably all over the molten ball. The erratic arc motion makes precision welding very difficult. The simple addition of 2%ThO_2 (thoria) to the tungsten allows tungsten electrodes to operate at currents of 200 amps easily without the electrode melting. Furthermore, the 2% thoria electrodes nor only operate without melting, but also can achieve greater electron emission than pure tungsten. Thoria is a very stable compound and has a melting point (over 3,000ºC or 5,500ºF) almost as high as tungsten (3,410ºC). The mechanism by which this happens depends on the high-temperature solid state reaction between tungsten (W) and ThO_2 to produce pure thorium (Th), as shown below:

$$W + ThO_2 \quad = \quad WO_2 + Th$$

At the very high temperatures experienced at the electrode tip during GTAW, the thorium diffuses to the outside surface of the electrode. During welding, the thorium-coated tungsten acts as if the electrode were entirely thorium. Thorium has a much lower work function than does tungsten. This means that the thorium-coated electrode can emit electrons with greater ease at lower temperatures than can tungsten. In fact, tungsten must be molten before it can achieve full thermionic emission of electrons. This is why AC welding of aluminum with pure tungsten electrodes requires that the tip of the tungsten be melted in the shape of a large ball. If pure tungsten does not have a melted ball at the electrode tip, the heat delivered by GTAW would be inadequate for welding because thermionic emission would not be achieved. The simple addition of 2%ThO_2 permits thermionic emission without having to melt the electrode using either DC or AC.
The current density achieved by 2%ThO_2-W electrodes is about 10,000,000 A/m^2.

Since ThO_2 is mildly radioactive, research had been conducted over the years to find a substitute for ThO_2. Ceria or CeO_2, which is not radioactive, was found to be an excellent replacement of ThO_2 as shown in Table 1, below.

Table 1 Tungsten electrode characteristic using argon shielding gas (Approximate values).

	W	W – 2%ThO_2	W – 2%CeO_2
Electrode Temperature, ºC	3,450	3,300	2,800
Work function, eV	3.0	2.4	2.1
Emissivity	0.15	0.22	0.30

From Table 1, the electron work function is highest with pure tungsten and lowest with W-CeO_2. The emissivity is lowest at the highest temperature for thermionic emission with pure tungsten; while, the emissivity of W- CeO_2 is highest at the lowest temperature. This means that both W-ThO_2 and W-CeO_2 electrodes can operate below their melting points, while achieving full thermionic emission of electrons in the weld arc. These additions to tungsten have the beneficial effect of increasing arc stability.

In automatic welding at high current continuously for long periods of time may cause excess evaporation of the thorium. If the surface thorium content is too low, the electrode may become unstable by acting like a pure tungsten electrode. The development of ceriated electrodes and lanthanated electrodes provide extended arc stability for automatic welding. These additions of CeO_2 and La_2O_3 diffuse much more slowly to the electrode surface because large tungstate and oxy-tungstate compounds form which are not very mobile at high temperatures. Thus, these ceriated and lanthanated electrodes have more long-term stability than thoriated electrodes.

Cleaning Action

For all practical purposes, there is no cleaning action when GTAW of steel. Thus, steel is rarely ever welded with DCEP or AC. The action of the cathode removing oxides does take place when GTAW steel and can be observed. However, the cleaning action effect is minor and not considered of any value in welding steel. In welding of aluminum and magnesium, this cleaning action is extremely important and beneficial. The reason why the oxide layer on steel does not “clean” nearly as well as that for aluminum is related to the chemical stability, oxide thickness, relative melting points between oxide and substrate, and dielectric or electrical insulating properties. The melting points of steel and iron oxide are not nearly as different as those for aluminum and aluminum oxide. Similarly, the difference in chemical stability between aluminum oxide and pure aluminum is very great; while the difference between steel and iron oxide is not as large. Thus, when welding with DCEP and the work piece is the cathode (negative pole), the electrons tend to build up charge to a much greater extent with the aluminum cathode than with the steel cathode. Eventually, the charge build-up becomes so great in the case of welding aluminum that the aluminum oxide layer is virtually exploded away from the surface or “cleaned”. The same action takes place with steel except it is not strong enough to be beneficial. Thus, steel is almost always welded with DCEN.

Common Power Source Controls

1. **WELD MODE KEYS**: These keys select the Weld mode desired, as the graphic symbols indicate the TIG 2-Step mode is selected when using a Foot Amptrol (foot operated remote current control), the TIG 4-Step is selected when using a Hand Amptrol (hand operated remote current control, usually mounted on the torch). The third mode is selected when using the power source for Stick welding.

2. **CURRENT CONTROL**: This area contains the Local/Remote keys as well as the Amps Up/Amps Down keys. The up/down keys are used to adjust amperage from 5 to 315 amps. The "Local" current control allows the current to be adjusted only with the Amps up/Amps down keys. The "Remote" current control is automatically activated when using the TIG 2-Step and TIG 4-Step modes.

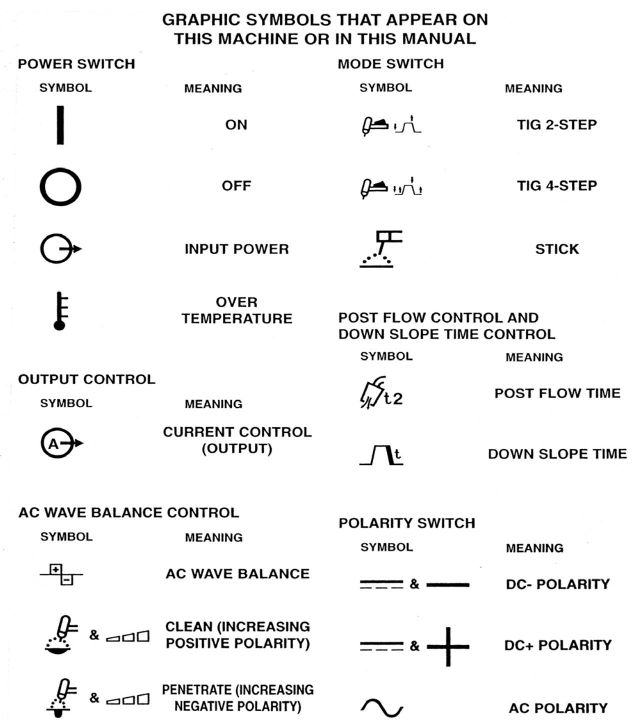
3. **HIGH FREQUENCY:** These keys are active in the TIG mode only. Select "Start Only" when using Direct Current straight polarity. Select "Continuous" when welding with Alternating Current. "Off" will automatically be selected when welding in the Stick mode.

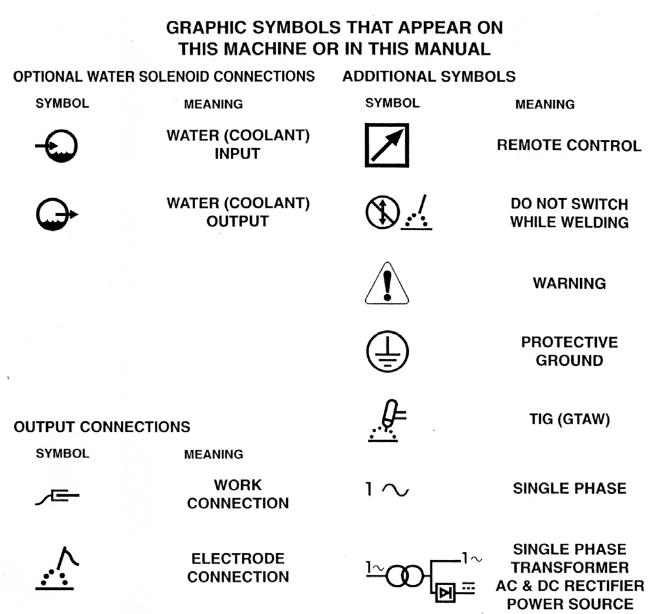
4. **AC WAVE BALANCE**: These keys are active in the AC TIG mode only. They are used to set the amount of cleaning and/or penetration. Auto Balance automatically sets the AC Wave balance according to the welding current.

5. **TIG PULSER**: These keys are active in the TIG mode only. The On/Off keys turn the pulse option on and off. The Pulses Per Second keys adjust the pulsing frequency up and down, from 0.5 to 10 pulses per second. The background current (the welding current at the low point of the pulse cycle) is automatically adjusted from 40% to 60% of the peak current (the welding current selected). The ratio between the time spent at peak current verses, the time spent at the background current is fixed at 50%.

6. **AFTERFLOW**: These keys are active in the TIG mode only. These keys adjust the length of time the gas flows after the arc is extinguished.

Common Graphic Symbols



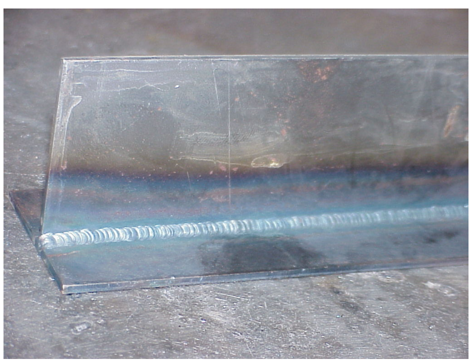


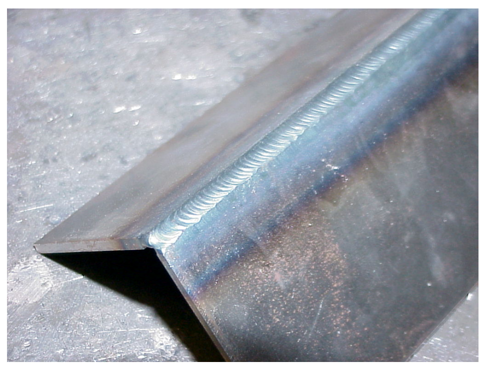
Craftsmanship Expectations for Welding Projects

Metal Preparation	**Project Layout**	**Weld Quality**
Thoroughly clean metal	Correct joint assembly (+/- 1/16")	See chart below

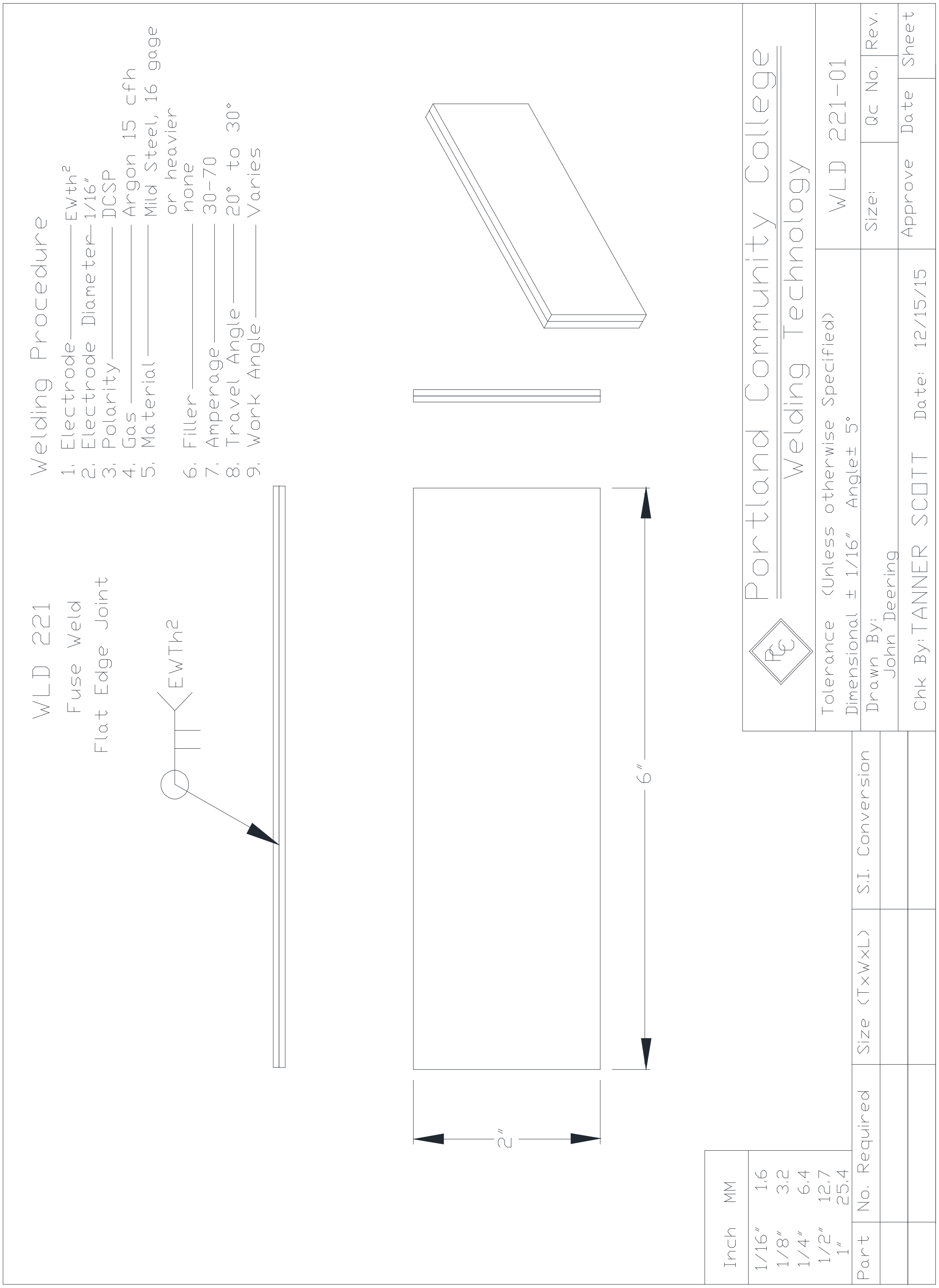
Weld Quality per Industry Standards

VT Criteria	**Cover Pass**
Weld Size	See specification on drawing
Undercut	1/32" deep
Weld Contour (Chevron spacing)	Smooth Transition
Penetration	N/A
Cracks	None Allowed
Arc Strikes	None Allowed
Fusion	Complete Fusion Required
Porosity	None Allowed
Overlap	None Allowed
Heat Input	Weld's shininess vs haziness

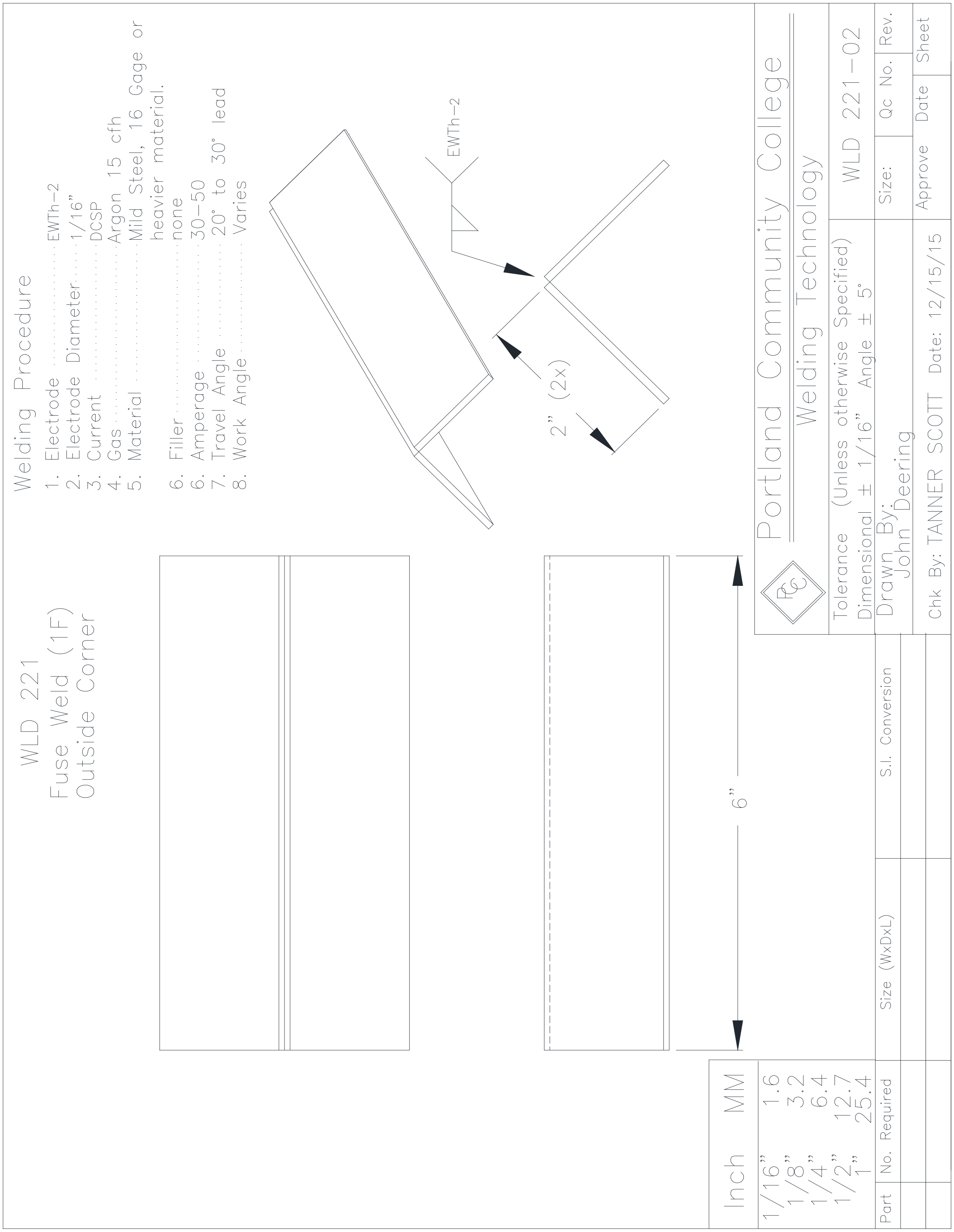


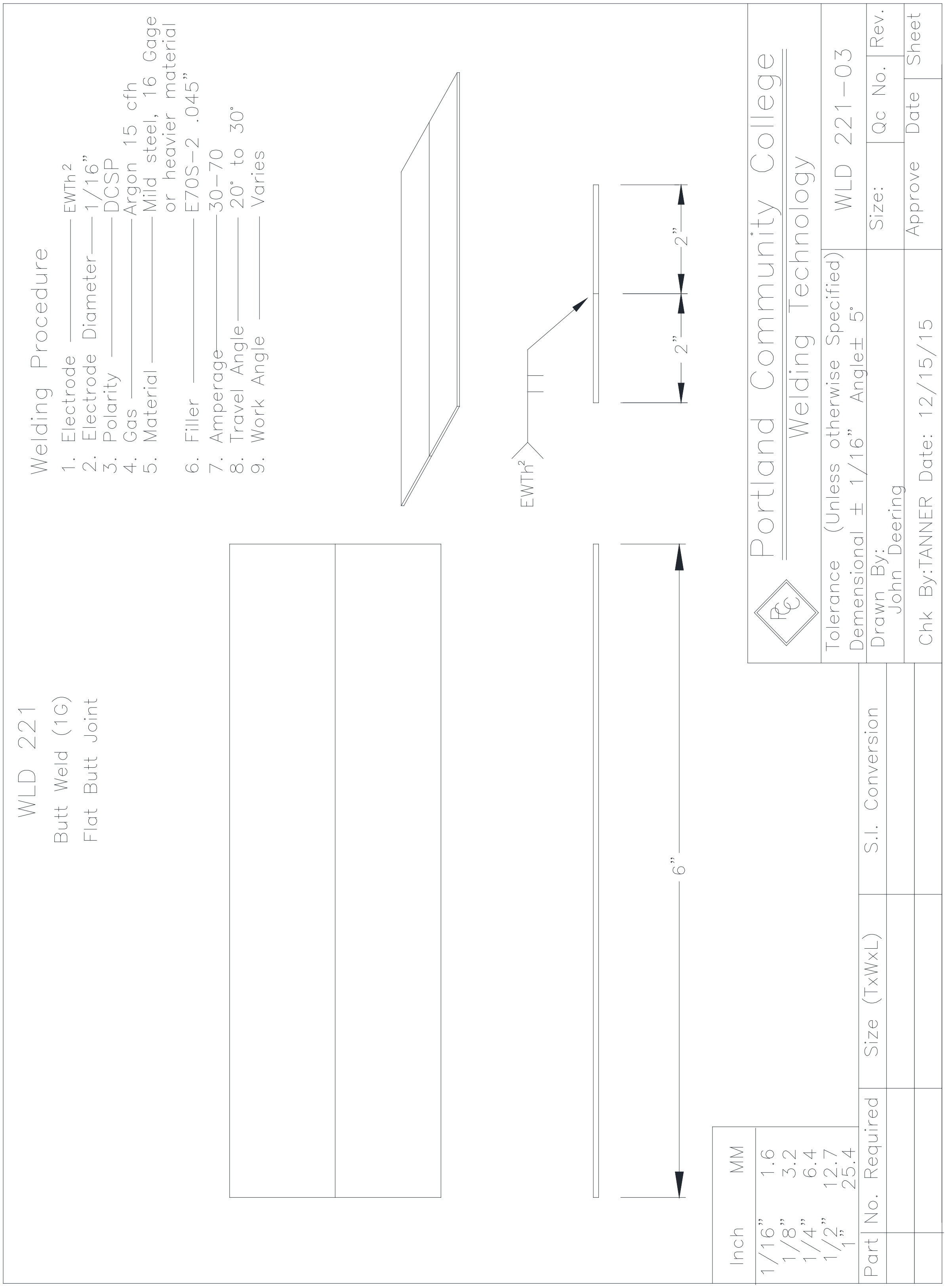


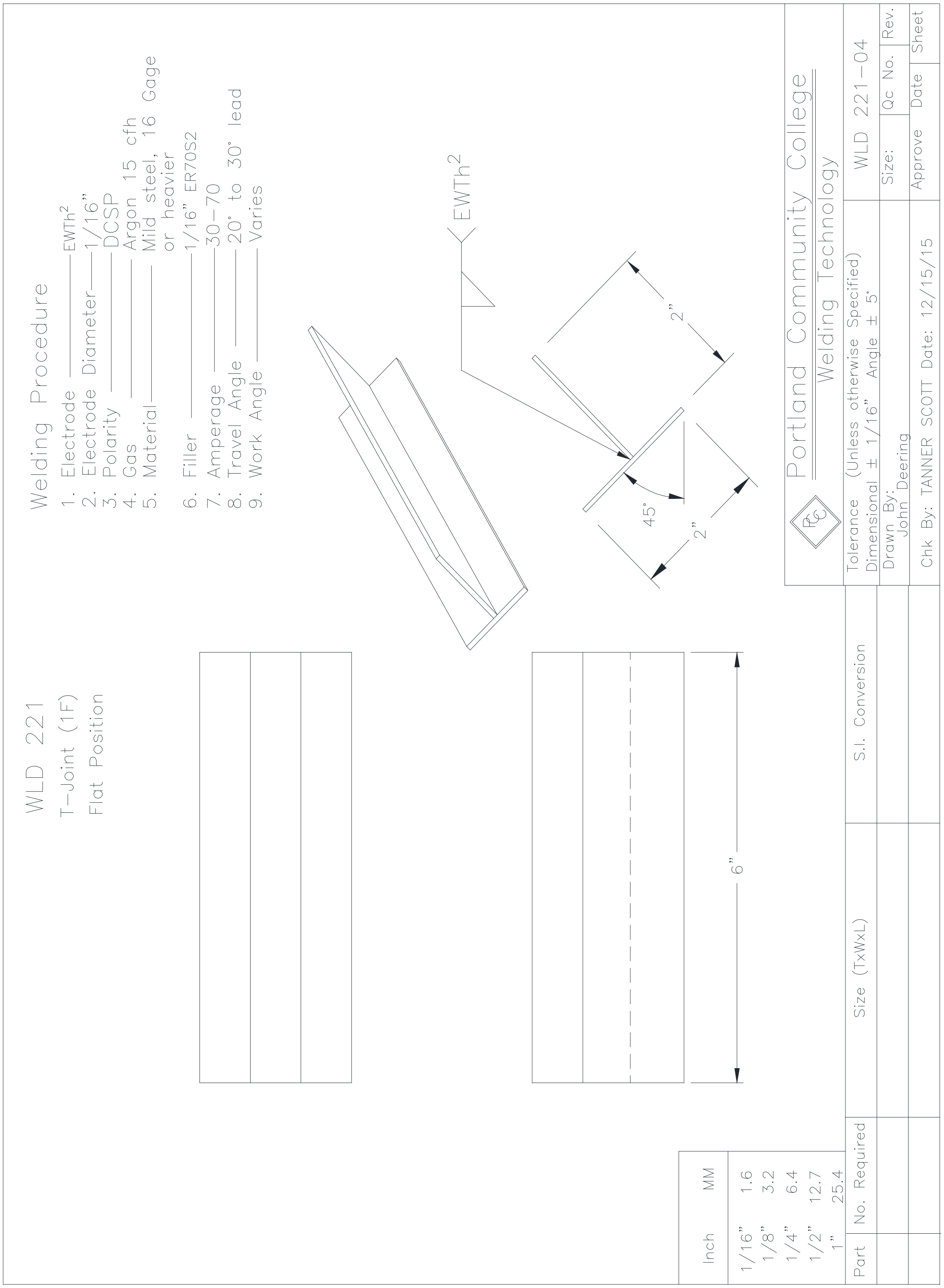
Example of a High-Quality Weld


WLD 221
Fuse Weld
Flat Edge Joint
EWTh2
Welding Procedure
1. Electrode — EWth2
2. Electrode Diameter — 1/16"
3. Polarity — DCSP
4. Gas — Argon 15 cfh
5. Material — Mild Steel, 16 gage or heavier
6. Filler — none
7. Amperage — 30-70
8. Travel Angle — 20° to 30°
9. Work Angle — Varies
6"
2"
Portland Community College
Welding Technology
Tolerance (Unless otherwise Specified)
Dimensional ± 1/16" Angle± 5°
Drawn By: John Deering
Chk By: TANNER SCOTT Date: 12/15/15
WLD 221-01
Size:
Qc No.
Rev.
Approve
Date
Sheet
Inch MM
1/16" 1.6
1/8" 3.2
1/4" 6.4
1/2" 12.7
1" 25.4
Part
No. Required
Size (TxWxL)
S.I. Conversion

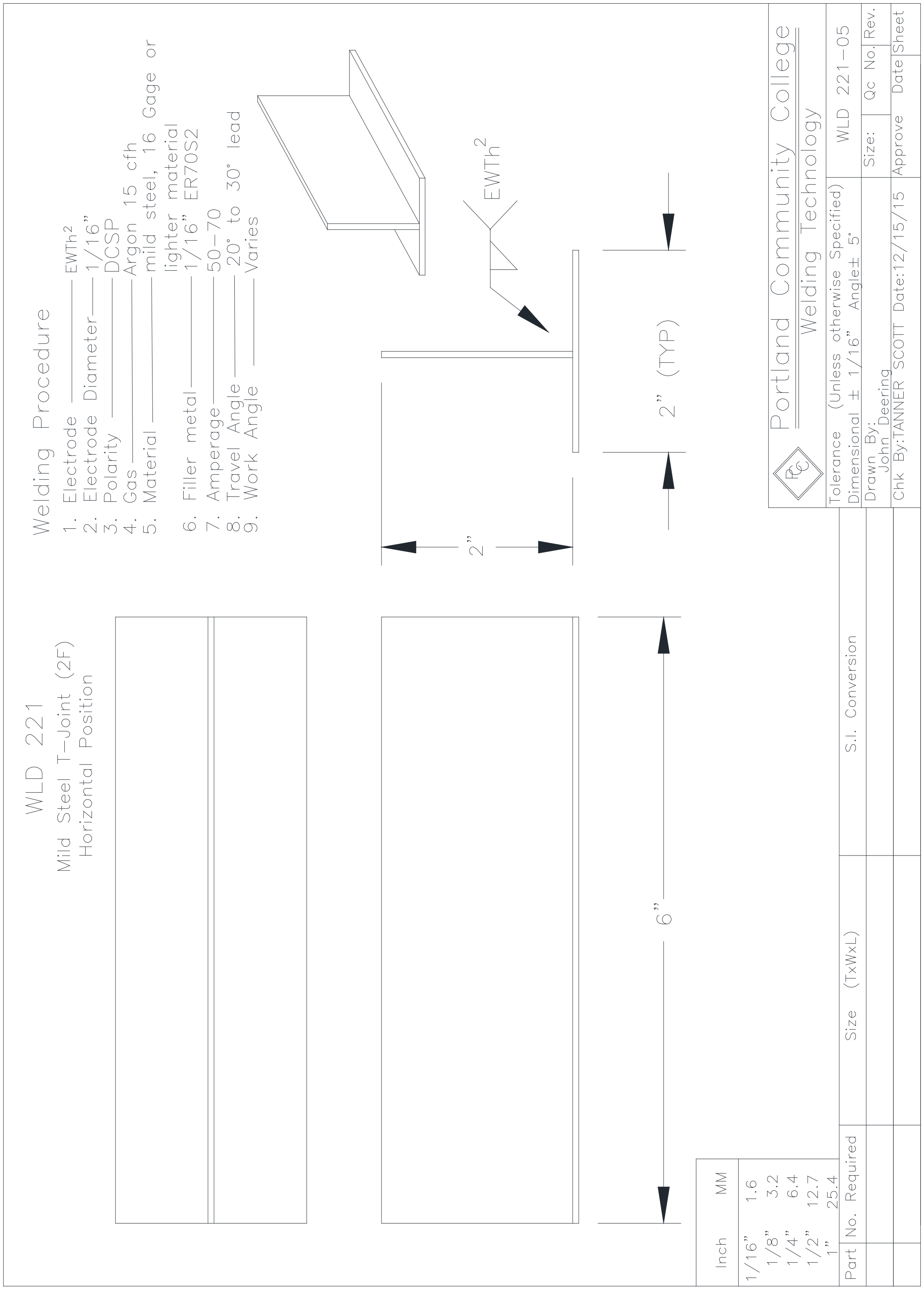
GTAW Flat Position Corner Joint (Fuse Weld)   Project #2



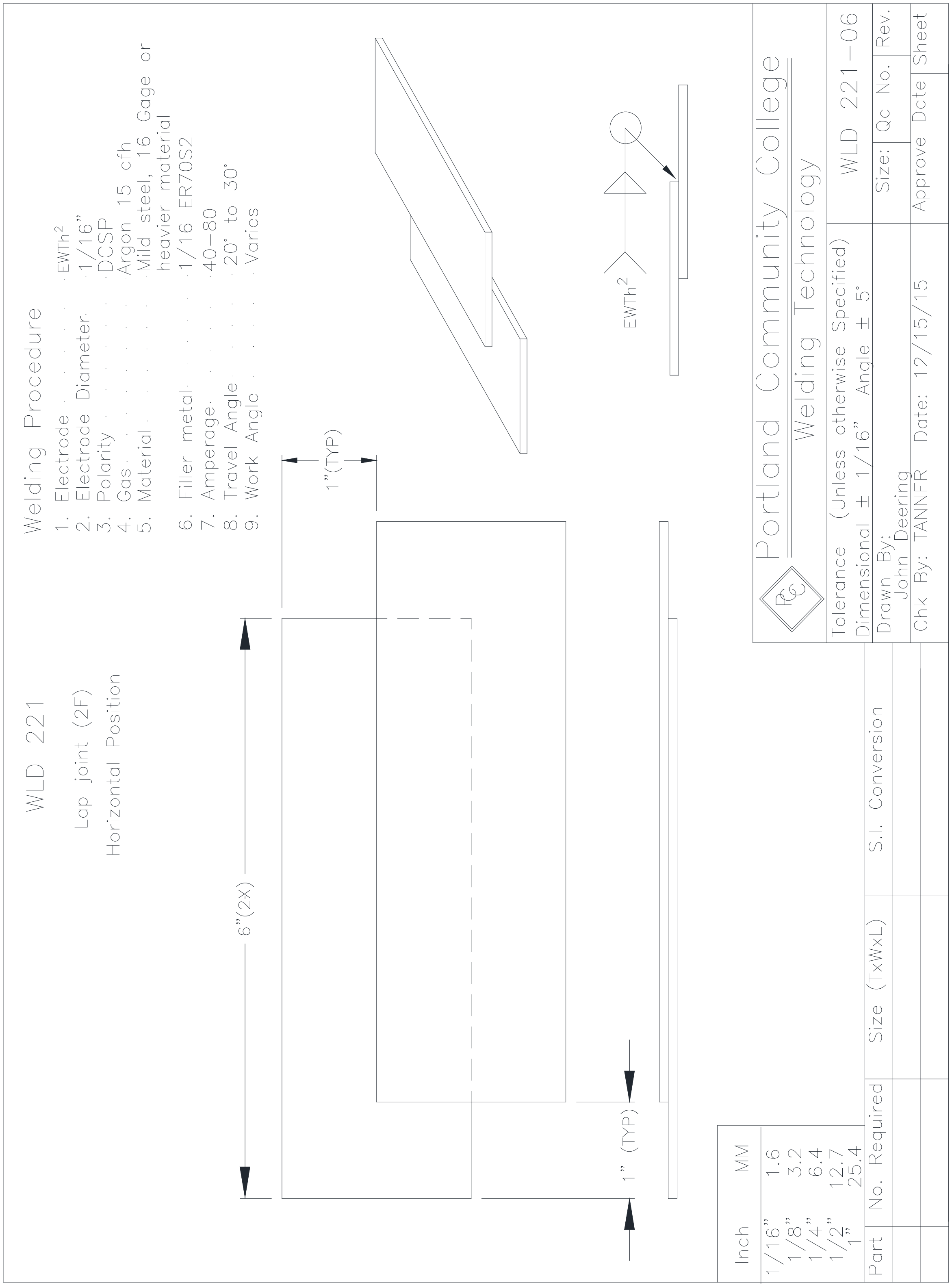

WLD 221
Butt Weld (1G)
Flat Butt Joint
Welding Procedure
1. Electrode — EWTh2
2. Electrode Diameter — 1/16"
3. Polarity — DCSP
4. Gas — Argon 15 cfh
5. Material — Mild steel, 16 Gage or heavier material
6. Filler — E70S-2 .045"
7. Amperage — 30-70
8. Travel Angle — 20° to 30°
9. Work Angle — Varies
EWTh2
2"
2"
6"
Inch MM
1/16" 1.6
1/8" 3.2
1/4" 6.4
1/2" 12.7
1" 25.4
Portland Community College
Welding Technology
Tolerance (Unless otherwise Specified)
Demensional ± 1/16" Angle± 5°
WLD 221-03
Drawn By: John Deering
Size:
Qc No.
Rev.
Chk By:TANNER Date: 12/15/15
Approve
Date
Sheet
Part No.
Required
Size (TxWxL)
S.I. Conversion

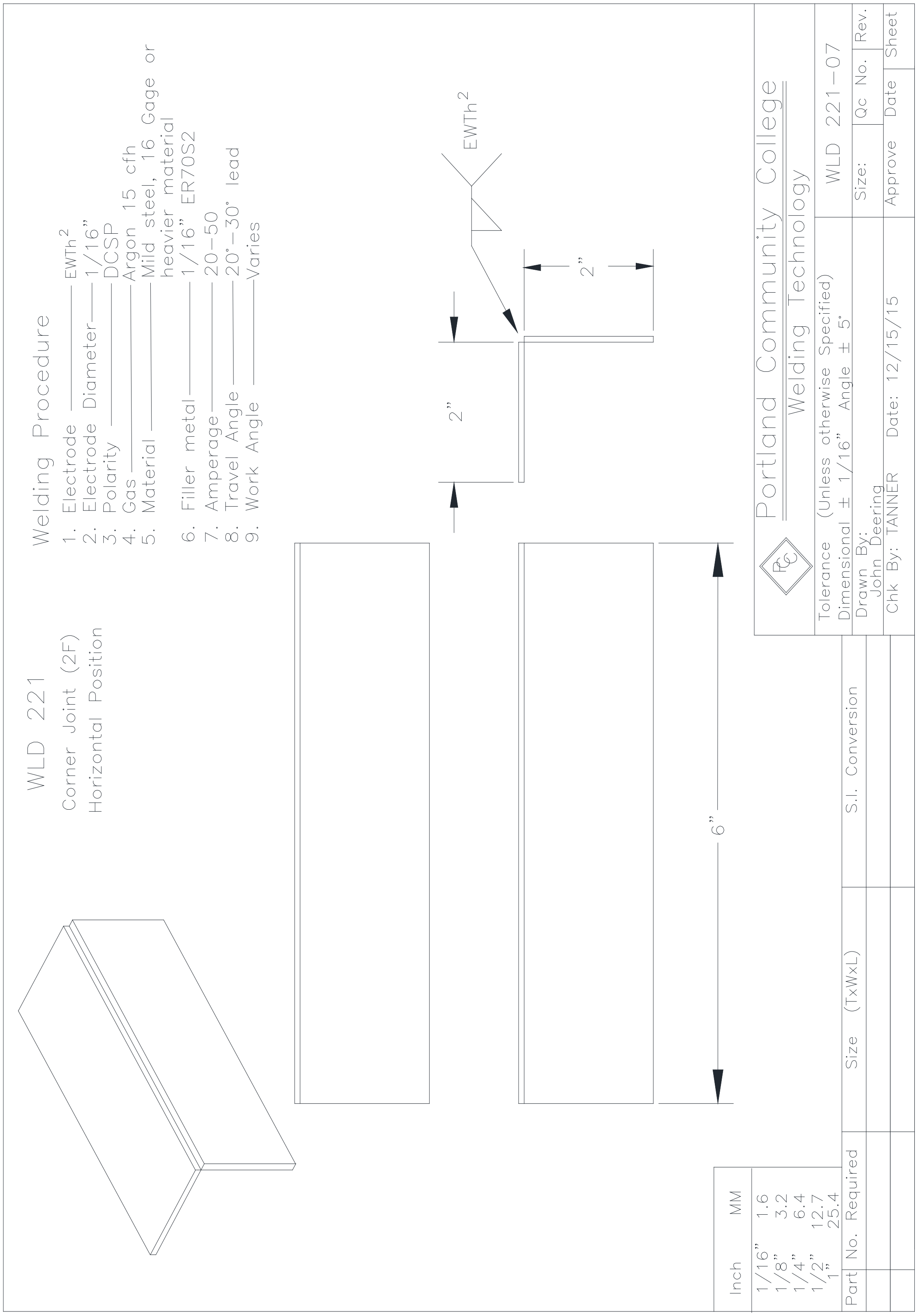

WLD 221
T-Joint (1F)
Flat Position
Welding Procedure
1. Electrode — EWTh2
2. Electrode Diameter — 1/16"
3. Polarity — DCSP
4. Gas — Argon 15 cfh
5. Material — Mild steel, 16 Gage or heavier
6. Filler — 1/16" ER70S2
7. Amperage — 30-70
8. Travel Angle — 20° to 30° lead
9. Work Angle — Varies
EWTh2
2"
45°
2"
6"
Portland Community College
Welding Technology
WLD 221-04
Tolerance (Unless otherwise Specified)
Dimensional ± 1/16" Angle ± 5°
Drawn By: John Deering
Chk By: TANNER SCOTT Date: 12/15/15
Size: Qc No. Rev.
Approve Date Sheet
Part No. Required Size (TxWxL) S.I. Conversion
Inch MM
1/16" 1.6
1/8" 3.2
1/4" 6.4
1/2" 12.7
1" 25.4

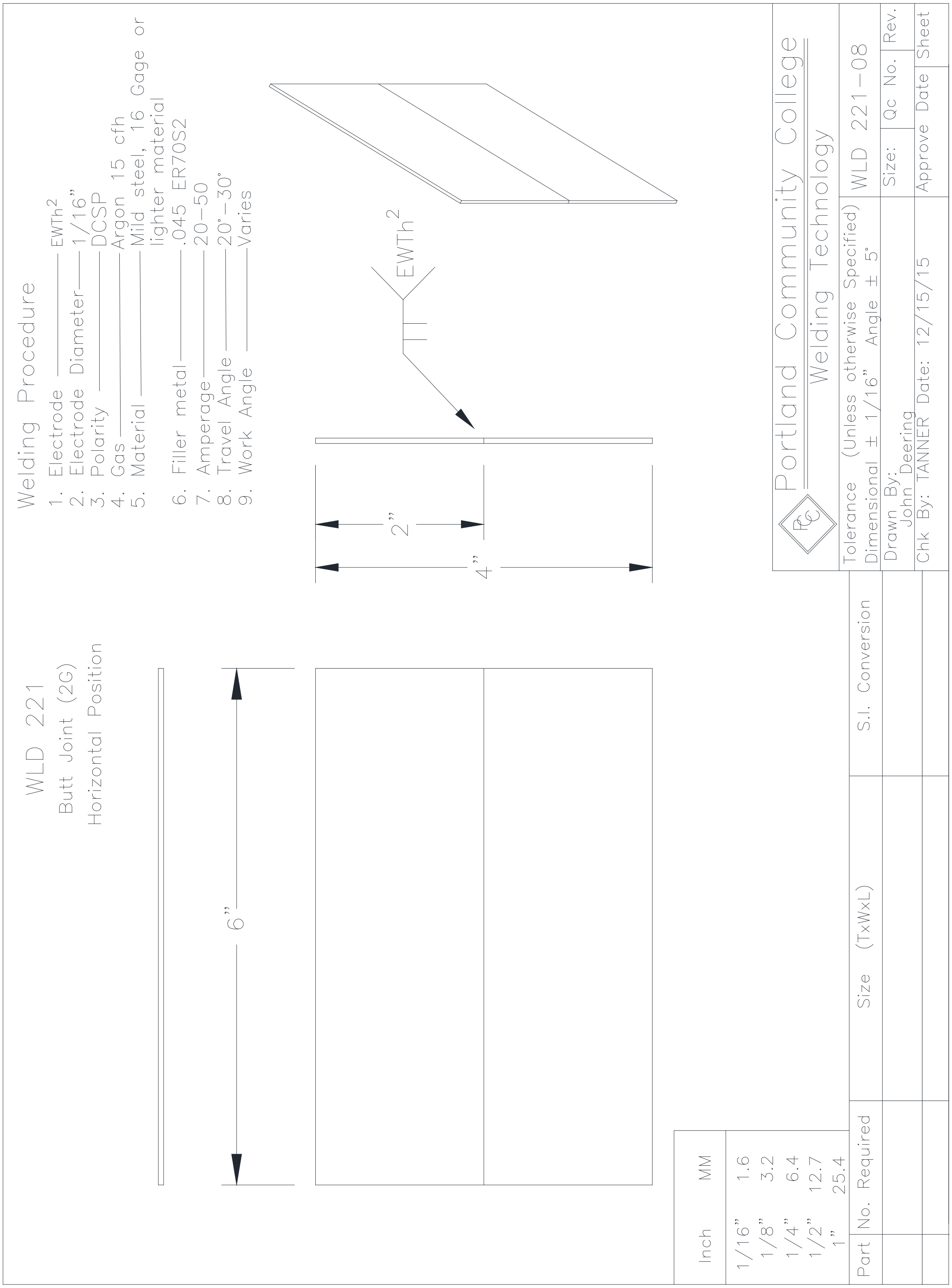
GTAW Horizontal T-Joint   Project #5



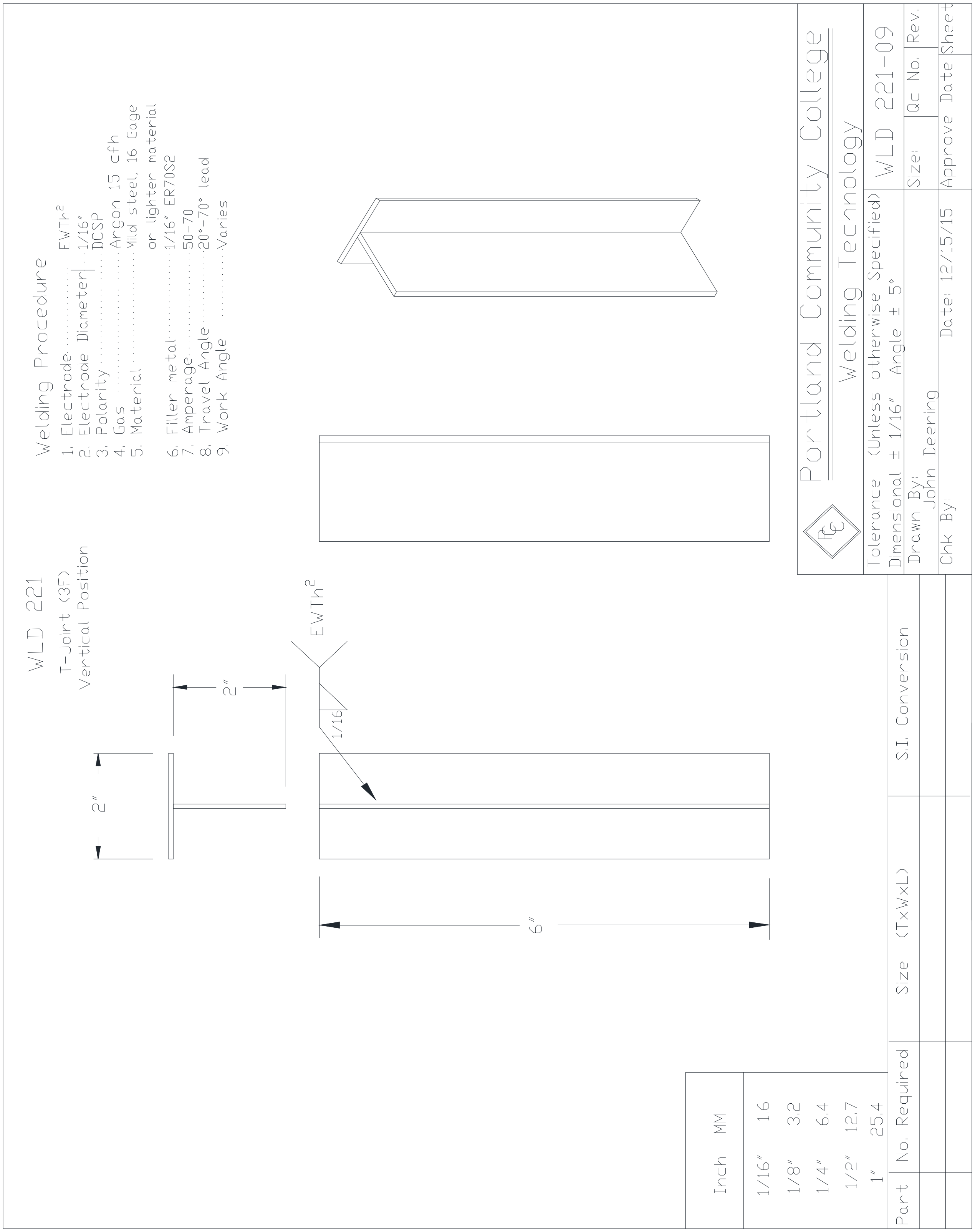
GTAW Horizontal Lap Joint Project #6

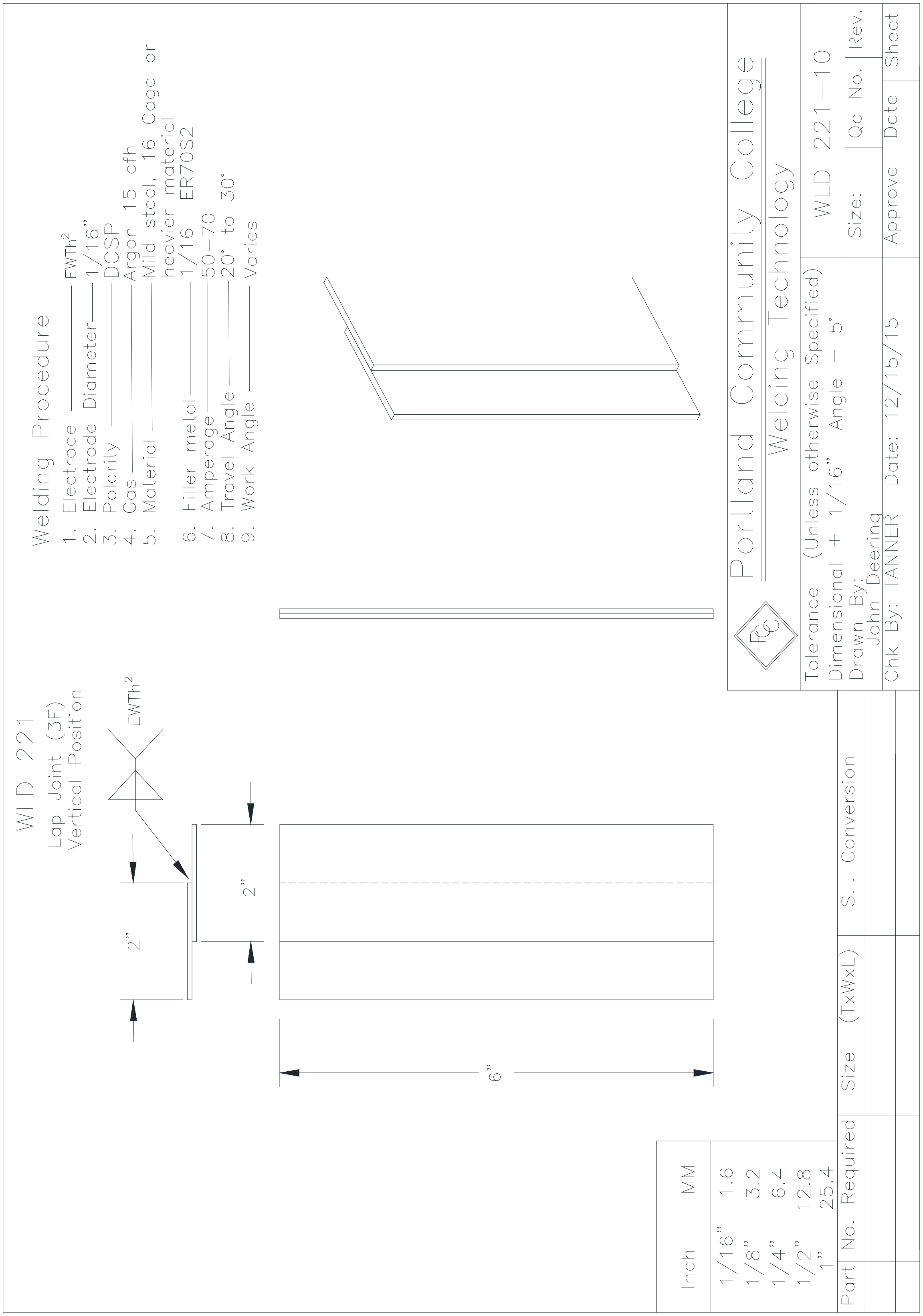



WLD 221
Corner Joint (2F)
Horizontal Position
Welding Procedure
1. Electrode — EWTh 2
2. Electrode Diameter — 1/16"
3. Polarity — DCSP
4. Gas — Argon 15 cfh
5. Material — Mild steel, 16 Gage or heavier material
6. Filler metal — 1/16" ER70S2
7. Amperage — 20-50
8. Travel Angle — 20°-30° lead
9. Work Angle — Varies
EWTh 2
2"
2"
6"
Inch MM
1/16" 1.6
1/8" 3.2
1/4" 6.4
1/2" 12.7
1" 25.4
Part No. Required
Size (TxWxL)
S.I. Conversion
Portland Community College
Welding Technology
Tolerance (Unless otherwise Specified)
Dimensional ± 1/16" Angle ± 5°
Drawn By: John Deering
Chk By: TANNER Date: 12/15/15
WLD 221-07
Size: Qc No. Rev.
Approve Date Sheet

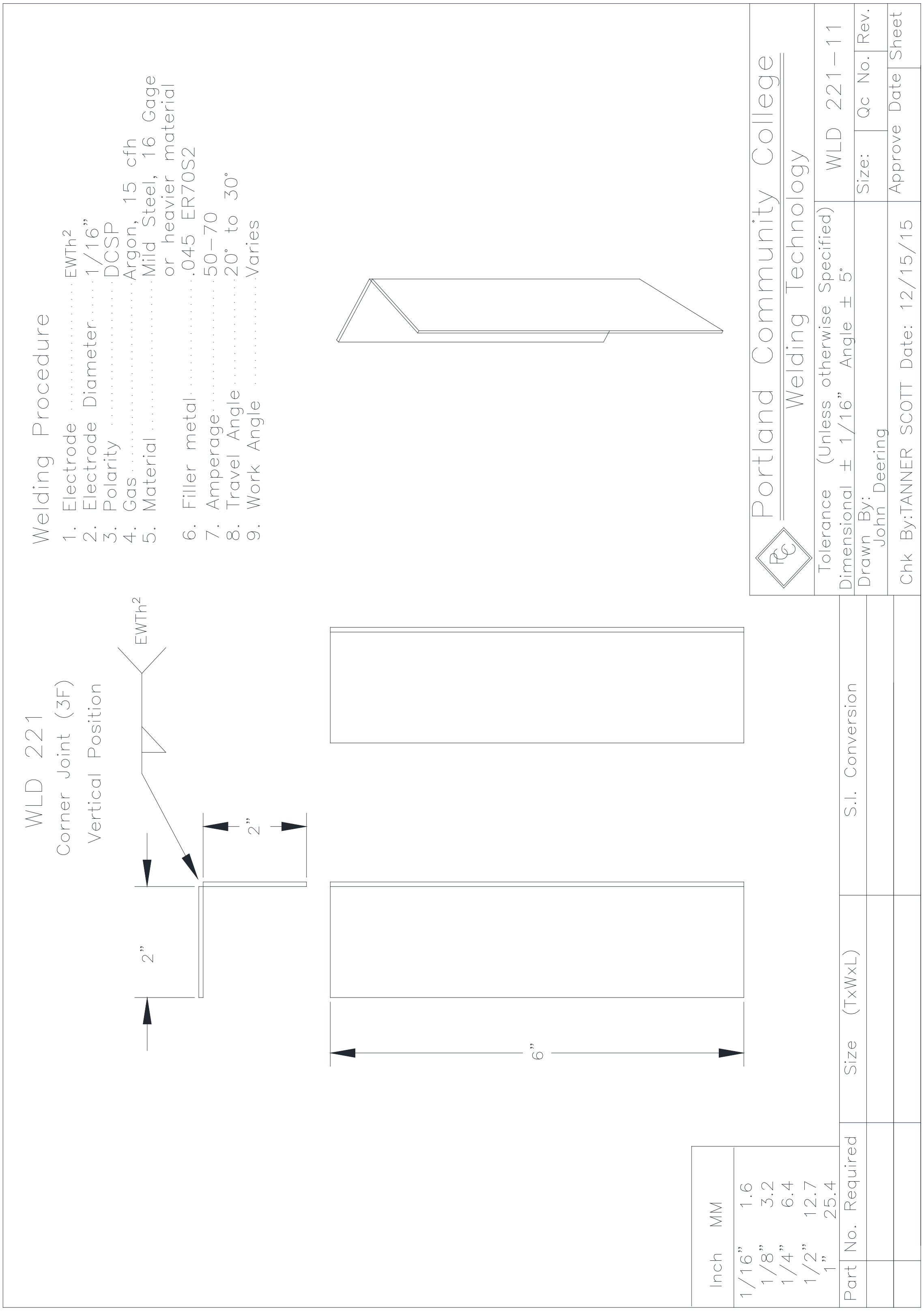

Welding Procedure
1. Electrode — EWTh2
2. Electrode Diameter — 1/16"
3. Polarity — DCSP
4. Gas — Argon 15 cfh
5. Material — Mild steel, 16 Gage or lighter material
6. Filler metal — .045 ER70S2
7. Amperage — 20-50
8. Travel Angle — 20°-30°
9. Work Angle — Varies
EWTh 2
2"
4"
WLD 221
Butt Joint (2G)
Horizontal Position
6"
Inch MM
1/16" 1.6
1/8" 3.2
1/4" 6.4
1/2" 12.7
1" 25.4
Portland Community College
Welding Technology
PCC
Tolerance (Unless otherwise Specified)
Dimensional ± 1/16" Angle ± 5°
WLD 221-08
Drawn By: John Deering
Size: Qc No. Rev.
Chk By: TANNER Date: 12/15/15
Approve Date Sheet
Part No. Required
Size (TxWxL)
S.I. Conversion

W Vertical T Joint Project #9

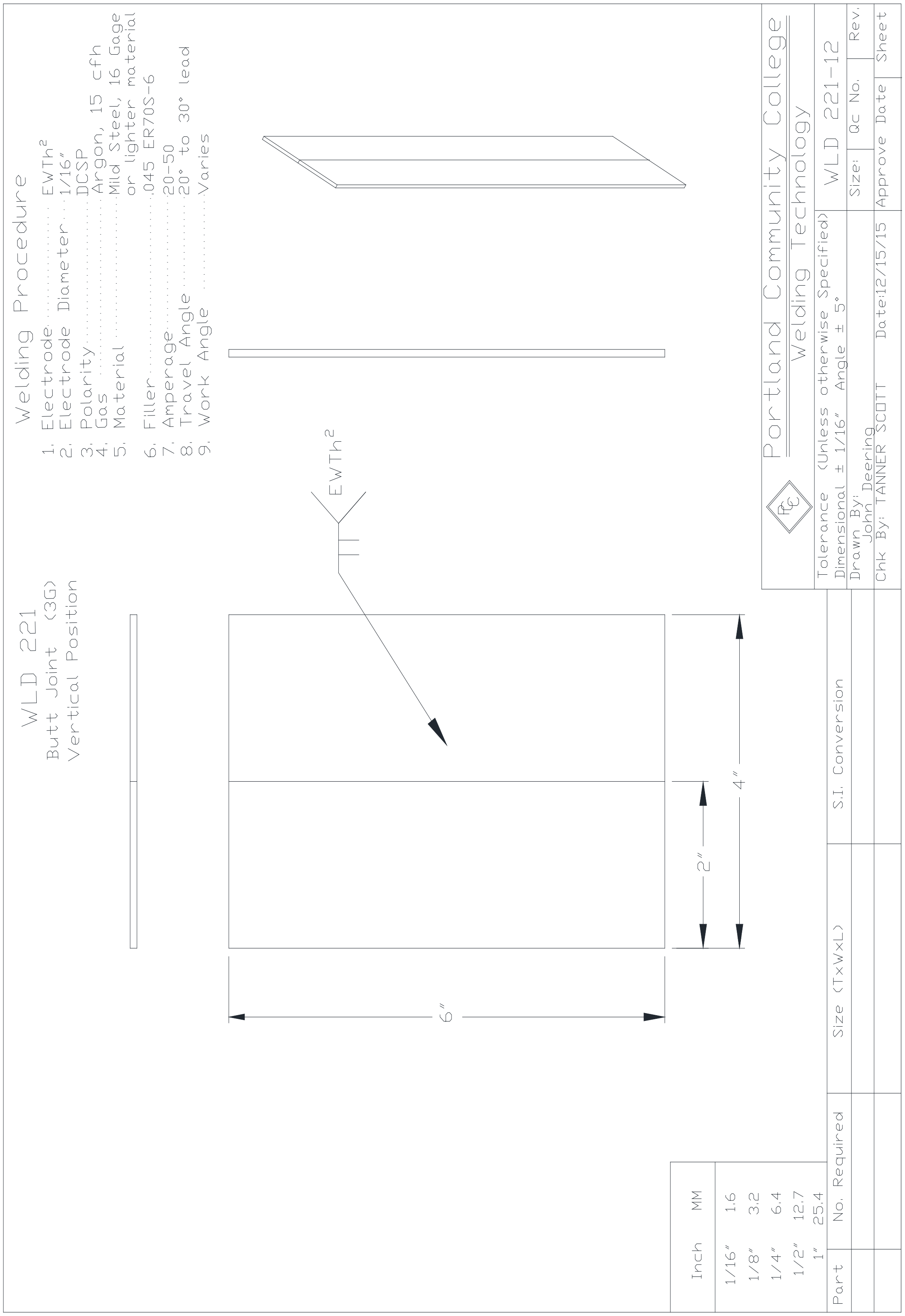



WLD 221
Lap Joint (3F)
Vertical Position
EWTh2
2"
2"
6"
Welding Procedure
1. Electrode — EWTh2
2. Electrode Diameter — 1/16"
3. Polarity — DCSP
4. Gas — Argon 15 cfh
5. Material — Mild steel, 16 Gage or heavier material
6. Filler metal — 1/16 ER70S2
7. Amperage — 50-70
8. Travel Angle — 20° to 30°
9. Work Angle — Varies
Inch MM
1/16" 1.6
1/8" 3.2
1/4" 6.4
1/2" 12.8
1" 25.4
Part No. Required Size (TxWxL) S.I. Conversion
Portland Community College
Welding Technology
Tolerance (Unless otherwise Specified)
Dimensional ± 1/16" Angle ± 5°
Drawn By: John Deering
Chk By: TANNER Date: 12/15/15
WLD 221-10
Size: Qc No. Rev.
Approve Date Sheet

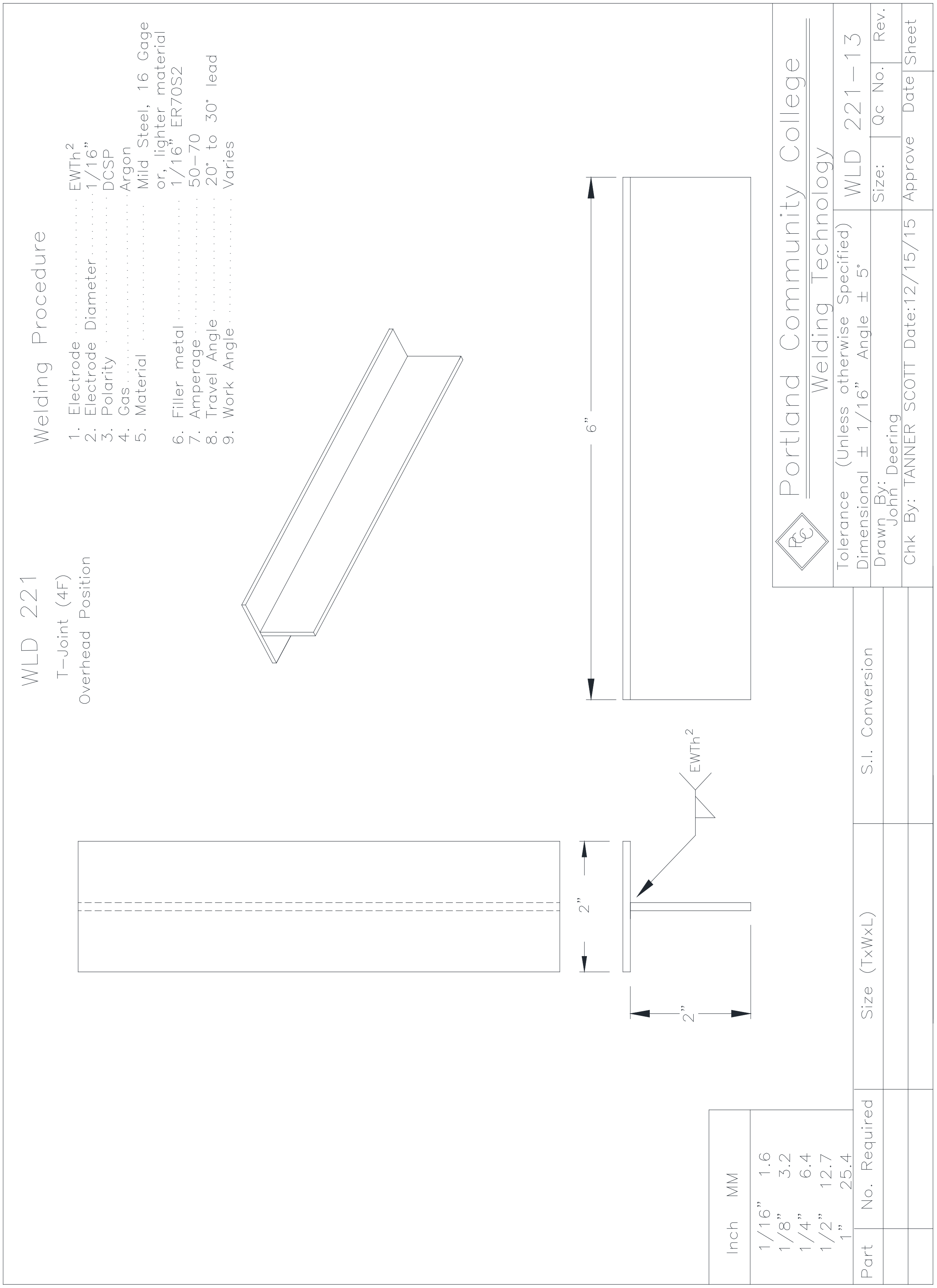
GTAW Vertical Position Corner Joint Project #11

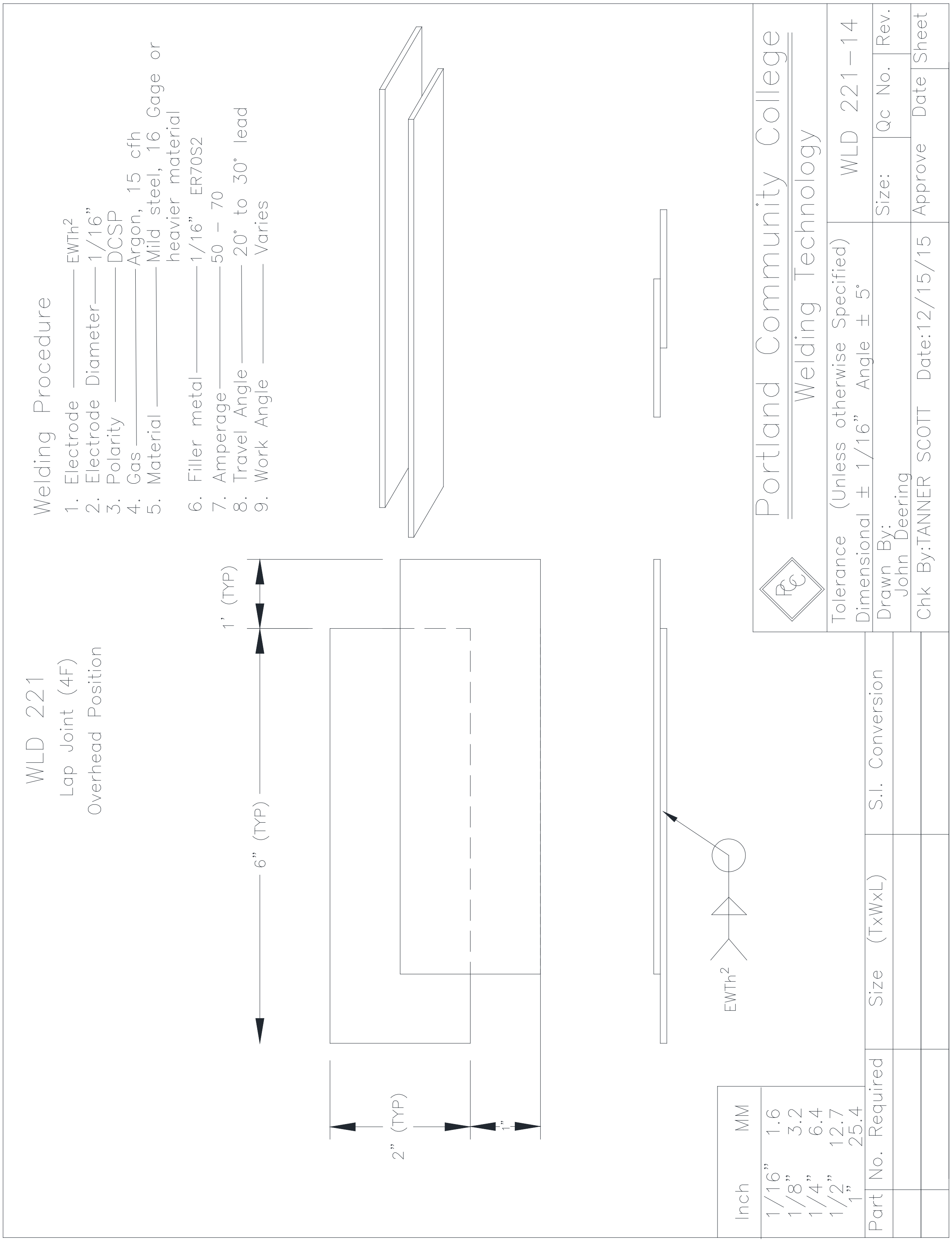


GTAW Vertical Position Butt Joint Project #12

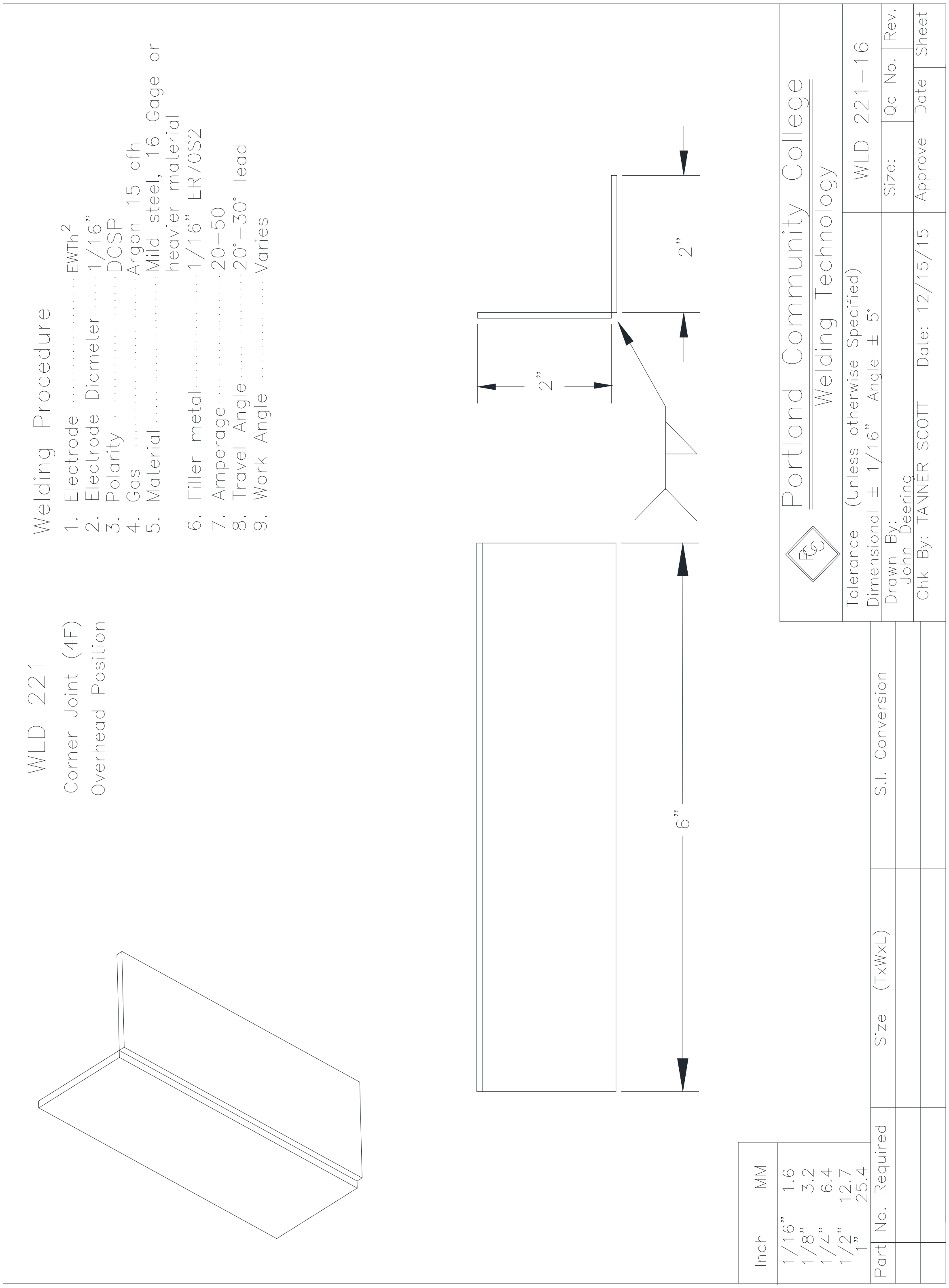


GTAW Overhead Position T Joint Project #13





WLD 221
Lap Joint (4F)
Overhead Position
Welding Procedure
1. Electrode — EWTh2
2. Electrode Diameter — 1/16"
3. Polarity — DCSP
4. Gas — Argon, 15 cfh
5. Material — Mild steel, 16 Gage or heavier material
6. Filler metal — 1/16" ER70S2
7. Amperage — 50 - 70
8. Travel Angle — 20° to 30° lead
9. Work Angle — Varies
6" (TYP)
1' (TYP)
2" (TYP)
1"
EWTh2
Inch MM
1/16" 1.6
1/8" 3.2
1/4" 6.4
1/2" 12.7
1" 25.4
Part No. Required
Size (TxWxL)
S.I. Conversion
Portland Community College
Welding Technology
WLD 221-14
Tolerance (Unless otherwise Specified)
Dimensional ± 1/16" Angle ± 5°
Drawn By: John Deering
Chk By:TANNER SCOTT Date:12/15/15
Size: Qc No. Rev.
Approve Date Sheet


WLD 221
Corner Joint (4F)
Overhead Position
Welding Procedure
1. Electrode .... EWTh 2
2. Electrode Diameter ..... 1/16"
3. Polarity .... DCSP
4. Gas .... Argon 15 cfh
5. Material .... Mild steel, 16 Gage or heavier material
6. Filler metal .... 1/16" ER70S2
7. Amperage 20-50
8. Travel Angle .... 20°-30° lead
9. Work Angle .... Varies
2"
2"
6"
Portland Community College
Welding Technology
WLD 221-16
Tolerance (Unless otherwise Specified)
Dimensional ± 1/16" Angle ± 5°
Drawn By: John Deering
Chk By: TANNER SCOTT
Date: 12/15/15
Size:
Qc No.
Rev.
Approve
Date
Sheet
Inch MM
1/16" 1.6
1/8" 3.2
1/4" 6.4
1/2" 12.7
1" 25.4
Part No. Required
Size (TxWxL)
S.I. Conversion

Final Exam

Part One
This portion of the final exam is a closed book test. Consult with your instructor to determine items that you may need to review. Once you determine that you are ready for the exam request the exam from your instructor. Complete the exam and write all answers on the answer sheet. Once completed, return the exam and answer sheet to your instructor.

Study Guide

Safety
- GTAW safety
- Hand Tool Safety

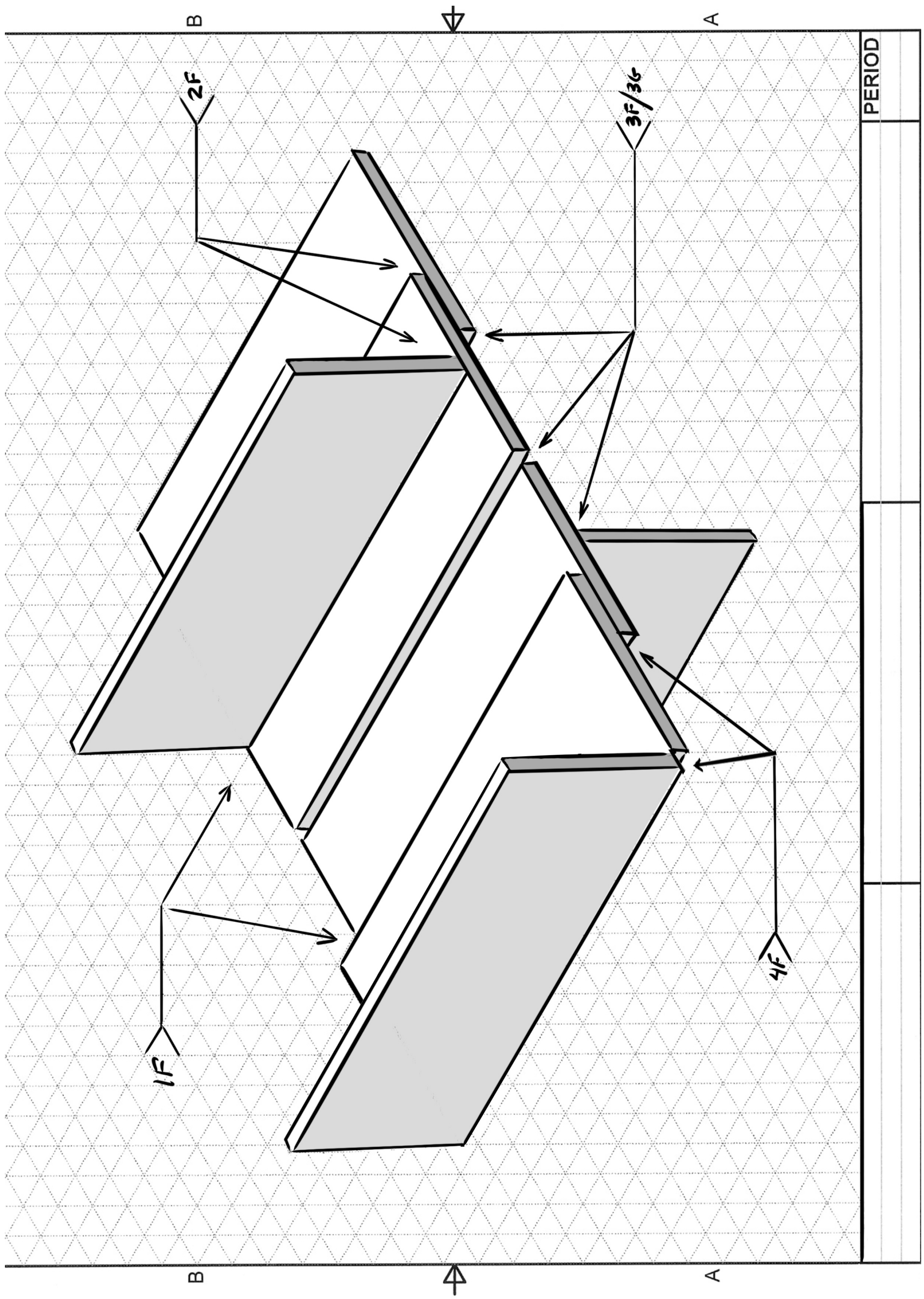
GTAW Processes
- Power source specifics
    - Polarity
    - Current out put
    - High Frequency
    - Shielding gases
        - Types
        - Pre/post flow
- AWS electrode classification
    - Color system

Welding Symbols and Blueprints
- Orthographic views
- Isometric views
- Welding symbol
    - Weld symbols
    - Reference line
    - Tail

Math and Math conversions
- Adding and subtracting fractions
- Reading a tape measure
- Metric conversions

Welding Flaws
- Porosity
- Tungsten Inclusions
- Bead profiles

Practical Exam: This portion of the final will be evaluated using the standard rubric.



Gas Tungsten Arc Welding – Equipment, Setup, Operation, and filler Metals
– Welding principals and applications: Larry Jeffus

Name: ________________________________ Date: _________

Introduction

1. GTAW is often referred to as TIG what do these two terms mean?

2. Why was the term Heliarc used in the past to describe the GTAW process?

3. What metals were weldable only with the GTAW process before GMAW was developed in the late 1940's?

Tungsten

4. What properties make tungsten the ideal non-consumable electrode for the GTAW process?

5. What is the melting temperature of tungsten?

6. What causes tungsten erosion?

7. Why can tungsten erosion be detrimental?

8. List eight ways to limit tungsten inclusion

9. What two ways can a collet be cooled?

10. Draw the three most common tungsten electrode shapes and label the polarity they are most commonly used for. (DCEP, DCEN, AC)

11. What are the drawbacks of using pure tungsten electrodes?

12. What are the benefits of adding Thorium the Tungsten electrode?

13. What is the benefit of adding Zirconium to the Tungsten electrode?

14. What is the benefit of adding Cerium to the Tungsten electrode?

15. Why were Cerium tungsten electrodes developed?

16. What is the befit of Lanthanum Tungsten?

17. What are the benefits of Rare Earth Tungsten electrodes?

18. How can the desired shape of the electrode end be obtained?

Torches

19. What are the benefits of a water-cooled welding torch?

20. What are the benefits of an air-cooled welding torch?

21. What material can a TIG welding nozzle or cup be made from?

22. What is the benefit of using a Gas Lens?

23. What is the purpose of a flow meter?

24. How is the rate of shielding gas flow measured?

Welding Current

25. What are the two standard types of welding current?

26. In what direction do electrons flow, negative to positive or positive to negative?

27. Describe the heat distribution between electrode and work while using DCEN.

28. Describe the heat distribution between electrode and work while using DCEP.

29. Describe the heat distribution between electrode and work while using AC.

30. What is the purpose of constant High Frequency when used with AC.

31. When welding with AC, which portion of the alternating current wave form provides a cleaning action, electrode positive or electrode negative?

32. It is often possible with newer welding power sources to change the EP and EN time of the welding current when welding with AC. Why might we adjust this balance?

33. Most manual GTAW is performed in what Hz range?

Gases

34. What are the two noble inert gasses used in the GTAW Process?

35. What two non-inert gasses can be added to argon?

36. What is “Hot Start”?

37. What is “pre-flow”?

38. What is “post-flow”?

39. What types of remote controls can be used with the GTAW process?

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40. What is the ideal torch angle?

41. Can torch angle effect gas coverage? If so how?

42. Why must the filler rod end be kept inside the protective zone of the shielding gas?

43. What is the benefit of leaving the filler metal in the weld pool while breaking the arc?

44. Why should the filler rod enter the gas as close to the base metal as possible?

45. RG60 or ER70S-3 are the preferred filler rod for GTAW WELDING OF low carbon and mild steels – why is the RG45 gas welding rod not recommended for GTAW welding?

Final Grading Rubric for practical exam
Class Name: WLD 221

Name:____ Date: ______________________________

Hold Points are mandatory points in the fabrication process, which require the inspector to check your work. You are required to follow the hold points.

Points Possible	***Hold Points***	***Instructor's Evaluation***
5 points	**Blueprint Interpretation and Material Cut List** 5 points = 0 errors, all parts labeled and sized correctly 3 points = 1 error in part sizing and/or identification 2 points = 2 errors 1 point = 3 errors 0 points = 4 or more errors	
10 points	**Material Layout and Cutting (Tolerances +/-1/16")** 10 points Layout and cutting to +/-1/16" Smoothness of cut edge to 1/32" 7 points Layout and cutting to +/- 1/8" Smoothness of cut edge to 1/16 **REWORK REQUIRED IF OUT OF TOLERANCE BY MORE THAN 1/8 INCH**	
10 points	**Fit-up and Tack weld (Tolerances +/- 1/16")** 10 points Tolerances +/- 1/16" Straight and square to +/-1/16" 7 Points Tolerances +/- 1/8" Straight and square to +/-1/8" **REWORK REQUIRED IF OUT OF TOLERANCE BY MORE THAN 1/8 INCH**	
15 points	**Weld Quality** Subtract 1 point for each weld discontinuity, incorrect weld size and incorrect spacing sequence.	
28 points	***Minimum points acceptable. This equates to the minimum AWS D1.1 Code requirements.***	
	Total Points	**/40**

WLD 221 GTAW Mild Steel: Project Assessment Form

Student Name:________________Date_________

Flat Position	Assessment	Instructor Signature/Date
Edge Joint – Fuse Weld		
Corner Joint – Fuse Weld		
Butt Joint		
T-Joint		

Horizontal Position	Assessment	Instructor Signature/Date
T-Joint		
Lap Joint		
Corner Joint		
Butt Joint		

Vertical Position	Assessment	Instructor Signature/Date
T-Joint		
Lap Joint		
Corner Joint		
Butt Joint		

Overhead Position	Assessment	Instructor Signature/Date
T-Joint		
Lap Joint		
Corner Joint		

Welding Projects average:
Written packet work:
Final written score:
Final practical rubric score: