

Block B: Tools and Equipment



Plumbing Apprenticeship Program Level 1 Series

Block B: Tools and Equipment

BC Plumbing Apprenticeship, Level 1

SKILLEDTRADESBC

*AUDREY CURRAN; MARK OVERGAARD; BC PIPING ARTICULATION AND
CURRICULUM SUBCOMMITTEE; AND PAUL SIMPSON*

TRU OPEN PRESS, THOMPSON RIVERS UNIVERSITY
KAMLOOPS, B.C.



Block B: Tools and Equipment Copyright © 2026 by Skilled Trades BC, TRU Open Press is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License (<https://creativecommons.org/licenses/by-nc-sa/4.0/>), except where otherwise noted.

Original material © SkilledTradesBC, All Rights Reserved. The original material provided by SkilledTradesBC has been adapted and modified with permission. ©COPYRIGHT TRU, 2026. Licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/deed.en>)) licence.

This licence allows you to retain, reuse, copy, redistribute, and revise this resource — in whole or in part — for **non-commercial purposes**, provided that the adapted version is released under the same licence and the original creators are properly attributed as follows:

Block B: Tools and Equipment (<https://b-handmeasuringtools-bcplumbingapprl1.pressbooks.tru.ca/>) by SkilledTradesBC, revised by the BC Articulation Curriculum Subcommittee, Audrey Curran, Mark Overgaard and TRU Open Press, is used under a CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/deed.en>) licence. **Download for free at:** <https://b-handmeasuringtools-bcplumbingapprl1.pressbooks.tru.ca/>

Suggested citation (APA 7th edition):

SkilledTradesBC. (2026). Block B: Tools and Equipment (Rev. ed.; adapted by Audrey Curran, Mark Overgaard, the BC Articulation Curriculum Subcommittee, & TRU Open Press). TRU Open Press, Thompson Rivers University.
<https://b-handmeasuringtools-bcplumbingapprl1.pressbooks.tru.ca/>

Cover art attribution:

This book was produced with Pressbooks (<https://pressbooks.com>) and rendered with Prince.

Contents

Block B: Tools and Equipment Introduction	1
Acknowledgements	5
Accessibility	xi
Part VI. B-6 Use Welding Equipment	
B-6 Use Welding Equipment Introduction	667
B-6.1 Describe Safety Requirements and Precautions for Arc Welding	669
B-6.2 Identify Types of Welds, Positions, Joints and Symbols	684
B-6.3 Describe the Arc Welding Process and Equipment	701
B-6.4 Use Arc Welding Equipment	718
Self-Test B-6.1: Describe Safety Requirements and Precautions for Arc Welding	735
Answer Key: Self-Test B-6.1	737
Self-Test B-6.2: Identify Types of Welds, Positions, Joints and Symbols	738
Answer Key: Self-Test B-6.2	741
Self-Test B-6.3: Describe the Arc Welding Process and Equipment	742
Answer Key: Self-Test B-6.3	744
Self-Test B-6.4: Use Arc Welding Equipment	745
Answer Key: Self-Test B-6.4	747
Version History	806
Plumbing Apprenticeship & Trade Resources in BC	807

Block B: Tools and Equipment of the Plumbing Apprenticeship Program Level 1 Series features Skilled Trades BC industry-authority content that builds on the safety foundations introduced in Block A by focusing on the correct selection, use, and care of essential plumbing tools and equipment. Safe work practices remain central, but the emphasis in this block is on developing hands-on technical competence in the tools apprentices use every day on the job.

In Block B, apprentices learn how to safely and effectively use hand tools and measuring tools; operate portable power tools; access work areas using ladders, scaffolds, and other access equipment; and perform rigging, hoisting, lifting, and positioning tasks. This block also introduces the safe use of soldering, brazing, oxy-fuel cutting, and welding equipment. Mastery of these skills supports workplace efficiency, reduces the risk of injury or equipment damage, and lays the groundwork for more advanced plumbing tasks in later levels of the apprenticeship.

Plumbing Apprenticeship Program Level 1 Series

The *Plumbing Apprenticeship Program Level 1 Series* offers comprehensive training materials designed to build on foundational skills and knowledge. The series is divided into four main blocks, each focusing on critical areas of plumbing systems and installations.

Block A: Safety Related Functions

(<https://a-safetyfunctions-bcplumbingapprii.pressbooks.tru.ca>)

A-1: Workplace Hazards

A-2: WorkSafeBC Regulations

A-3: Safe Handling of Hazardous Materials

A-4: Personal Safety Practices

A-5: Fire Safety

Block B: Tools and Equipment

(<https://b-handmeasuringtools-bcplumbingapprii.pressbooks.tru.ca>)

B-1: Use Hand Tools and Measuring Tools

B-2: Use Portable Power Tools and Use

B-3: Use Access Equipment

B-4: Use Rigging, Hoisting, Lifting and Positioning Equipment, and Rigging

B-5: Use Soldering and Brazing Equipment and Oxy-Fuel Cutting Equipment

B-6: Use Welding Equipment

Block C: Routine Trade Activities and Electrical Concepts (<https://c-tradeactivities-electrical-bcplumbingappri1.pressbooks.tru.ca>)

- C-1: Mathematics and Science
- C-2: Electrical Concepts and Principles of Electricity
- C-3: Drawings and Specifications
- C-4: Codes, Regulations and Standards
- C-5: Manufacturer and Supplier Documentation

Block D: Piping and Components (<https://d-pipingcomponents-bcplumbingappri1.pressbooks.tru.ca>)

- D-1: Install Pipe and Tubing
- D-2: Install Valves
- D-3: Install Fittings
- D-4: Penetrate Structures

Plumbing Apprenticeship Program Overview and Upcoming Resources

- **Plumbing Apprenticeship Program Level 1 Series** (<https://openpress.trubox.ca/2024/12/13/plumbing-apprentice-level-1/>) can be found in the TRU Open Press Collection.
- **Plumbing Apprenticeship Program Level 2 Series** (<https://openpress.trubox.ca/2024/04/26/bc-plumbing-apprenticeship-level-2/>) can be found in the TRU Open Press Collection.
- **Plumbing Apprenticeship Program Level 3 Series** (<https://collection.bccampus.ca/search/?q=%22pl3%22>) can be found in the BCCampus Open Collection (<https://collection.bccampus.ca/>).
- **Plumbing Apprenticeship Program Level 4 Series** (<https://bccampus.ca/projects/archives/zed-cred-z-degrees/ztc-open-educational-resources-for-trades/>) can be found in the BCCampus Open Collection. (<https://collection.bccampus.ca/>) (Block F: Commission and Service will be available soon.)

Disclaimer

The materials in these Learning Guides are intended for use by students and instructional staff. They have been compiled from sources believed to be reliable and to represent the best current opinions on these subjects. These manuals are designed to serve as a starting point for good practices and may not cover all minimum legal standards. No warranty, guarantee, or representation is made by the BC Piping Trades Articulation Committee, the Skilled Trades BC authority, or the King's Printer of British Columbia regarding the accuracy or sufficiency of the information contained in these publications. These manuals aim to provide basic guidelines for piping trades practices. Therefore, do not assume that all necessary warnings and safety precautions are included, and additional measures may be required.

Safety Advisory

The current Standards and Regulation in BC can be obtained at the WorkSafeBC website: <http://www.worksafebc.com> (<http://www.worksafebc.com>)

Please note that it is always the responsibility of any person using these materials to inform themselves about the Occupational Health and Safety Regulation pertaining to their areas of work.

[From previous 2021 book – confirm this message with Skilled Trades]

Symbol Legend



Important Information



Potentially Toxic/ Poisonous Situation



Required or Optional Resources



Potentially Flammable Situation



Complete a Self-Test



Possibly Explosive Situation



Use Protective Equipment



Potential Electric Shock

Acknowledgements

The development of the *Plumbing Apprenticeship Level 1* learning resources was a collaborative effort driven by a commitment to excellence in trades education. These resources were created to support apprentices and journeypersons in mastering the skills and knowledge essential to the piping trades. This achievement would not have been possible without the dedication and expertise of *Skilled Trades BC* and the *Piping Trades Articulation Committee*, whose contributions, leadership, and guidance have been instrumental in shaping high-quality, industry-aligned training resources. We extend our sincere gratitude for their contributions and ongoing stewardship in advancing the piping trades.

The content for *Block B: Tools and Equipment* (<https://b-handmeasuringtools-bcplumbingapprl1.pressbooks.tru.ca/>) is adapted from the Piping Trades Apprenticeship Program from *SkilledTradesBC* (2019 Harmonized) and the Trades Access Common Core (TACC) (<https://collection.bccampus.ca/search/?q=%22Trades%20Access%20Common%20Core%22>) resources developed by Camosun College, originally created in 2015, revised in 2019, and made available through BCcampus:

- Line C: Tools and Equipment: Competency C-1: Describe Common Hand Tools and Their Uses (<https://collection.bccampus.ca/resource/BzEe9fcq>)
- Line C: Tools and Equipment: Competency C-2: Describe Common Power Tools and Their Uses (<https://collection.bccampus.ca/resource/zAYtfTec>)
- Line C: Tools and Equipment: Competency C-3: Describe Rigging and Hoisting Equipment (<https://collection.bccampus.ca/resource/hDUEqpfn>)
- Line C: Tools and Equipment: Competency C-4: Describe Ladders and Work Platforms (<https://collection.bccampus.ca/resource/7c8Ymhmk>)

The original materials were produced in collaboration with industry partners and aligned with the Industry Training Authority (ITA) / *SkilledTradesBC* harmonized program outlines for Plumbing, Steamfitting/Pipefitting, and Sprinkler Fitting. These works were released under a Creative Commons Attribution 4.0 International (CC BY 4.0 (<https://creativecommons.org/licenses/by/4.0/>)) licence, except where otherwise noted.

This TRU Open Press edition includes editorial revisions, updated content, and the addition of new images, alongside selected images carried forward from the original Camosun College/BCcampus edition. Images in this work are licensed separately under their respective Creative Commons licences or the public domain, as credited in individual figure captions or attribution statements, unless otherwise noted. All images originally copyright the BC Industry Training Authority are licensed under the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International licence (CC-BY-NC-SA (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)).

This adapted version has been reformatted and integrated into the current Thompson Rivers University / TRU Open Press open educational resource in collaboration with the BC Piping Articulation and Curriculum Subcommittee and *SkilledTradesBC*, in support of open, accessible, and up-to-date apprenticeship training.



The Open Press

The Open Press combines TRU's open platforms and expertise in learning design and open resource development to support the creation and reuse of open educational resources, while encouraging open scholarship and research.

Resource Development Team 2024-2026

Content Review, Revision, and Development: BC Plumbing Articulation Curriculum Subcommittee and Audrey Curran

Final Content Review and Revisions: Audrey Curran and Mark Overgaard, BCIT

Project Lead (TRU Plumbing Trades): Paul Simpson, Curriculum Subcommittee Chair

Author: SkilledTradesBC

Publishing Manager/ Copy Editing: Dani Collins, MEd

Production: Jessica Obando Almache, BCS

- Co-op Students:
 - Greg Vilac
 - Riley Phillips
 - Vansh Sethi
 - Jesse Perkins, BCS Co-op Student
 - Daniel Abdulai
 - Kobe Shimoyama
 - Jose Contreras Antequera

Resources

Content adapted from:

- ©2019, Skilled Trades BC (Harmonized)
- Open School BC
- Camosun College
- Trades Training BC

For the latest BC Plumbing Trades Program Outline (2025), see the SkilledTradesBC website: www.skilledtrades.bc.ca (<https://skilledtradesbc.ca/>)

To order printed copies of Program Outlines or learning resources (where available) for BC Trades, contact:

Crown Publications, King's Printer

Web: www.crownpub.bc.ca

Email: crownpub@gov.bc.ca

Toll Free: 1 800 663-6105

The topics in this book are aligned with the competencies in the Industry Training Authority Program Outlines for the Piping Trades:

- Piping Trades Apprenticeship Program – Perform Safety Related Functions – Level 1 Harmonized (2019) (Binder) (ISBN: 978-0-7726-7362-6; product no. 7960000260) Crown Publications Online Catalogue – Piping Trades Apprenticeship Program – Perform Safety Related Functions – Level 1 Harmonized (2019) (Binder) (https://www.crownpub.bc.ca/Product/Details/7960000260_S)
- Piping Trades Apprenticeship Program – Use Tools and Equipment – Level 1 Harmonized (2019) (Binder) (ISBN: 978-0-7726-7362-6; Product no. 7960000261) Crown Publications Online Catalogue – Piping Trades Apprenticeship Program – Use Tools and Equipment – Level 1 Harmonized (2019) (Binder) (https://www.crownpub.bc.ca/Product/Details/7960000261_S)
- Piping Trades Apprenticeship Program – Perform Routine Trade Activities and Apply Electrical Concepts – Level 1 Harmonized (2019) (Binder) (ISBN: 978-0-7726-7362-6; product no. 7960000262) Crown Publications Online Catalogue – Piping Trades Apprenticeship Program – Perform Routine Trade Activities and Apply Electrical Concepts – Level 1 Harmonized (2019) (Binder) (https://www.crownpub.bc.ca/Product/Details/7960000262_S)
- Piping Trades Apprenticeship Program – Prepare Piping and Components – Level 1 Harmonized (2019) (Binder) (ISBN: 978-0-7726-7362-6; product no. 7960000263) Crown Publications Online Catalogue – Piping Trades Apprenticeship Program – Prepare Piping and Components – Level 1 Harmonized (2019) (Binder) (https://www.crownpub.bc.ca/Product/Details/7960000263_S)

The following suppliers have kindly provided copyright permission for selected images:

- RIDGID TOOLS/Emerson Professional Tools (EPT): All RIDGID tool images are used with permission from Emerson Professional Tools. Some of these images may have been adapted and carried forward from SkilledTradesBC learning resources; however, permission has been obtained directly from Emerson Professional Tools for their use here.

Any additional adapted versions of this content would require additional copyright permissions from the rights holders.

Creative Commons and site licensed images:

- Cover B-1: Red and Yellow Hand Tools on the Table (<https://www.pexels.com/photo/red-and-yellow-hand-tools-on-the-table-4312860/>) is by Anna Shvets on pexels, used as per the Pexels License. (<https://www.pexels.com/license/>)
- Cover B-2: A Person in Plaid Shirt Using a Power Tool (<https://www.pexels.com/photo/a-person-in-plaid-shirt-using-a-power-tool-8961527/>) by Mikael Blomkvist on Pexels, is used under the Pexels License. (<https://www.pexels.com/license/>)
- Cover B-3: Men on Brown Scaffolding, (<https://www.pexels.com/photo/men-on-brown-scaffolding-2209529/>) by Darya Sannikova, on Pexels, is used under the Pexels License. (<https://www.pexels.com/license/>)
- Cover B-4: Yellow crane hook against blue sky, (<https://www.pexels.com/photo/yellow-crane-hook-against-blue-sky-in-para-brazil-33346841/>) by Julia Nobre, on Pexels, is used under the Pexels License. (<https://www.pexels.com/license/>)
- Cover B-5: Propane torch soldering copper pipe, (https://commons.wikimedia.org/wiki/File:Propane_torch_soldering_copper_pipe.jpg) by Kevin L Neff via Wikimedia Commons, is used under a CC BY 2.0 (<https://creativecommons.org/licenses/by/2.0>) license.
- Cover B-6: Person in Welding Mask While Welding a Metal Bar, (<https://www.pexels.com/photo/person-in-welding-mask-while-welding-a-metal-bar-73833/>) by Pixabay, on Pexels, is used under the Pexels License. (<https://www.pexels.com/license/>)
- **All other CC-licensed, site-licensed, and public domain images are attributed in the sections where they appear.**

All symbol icons are from the Noun Project and are used under a CC BY license:

- Important by Larea from Noun Project (<https://thenounproject.com/browse/icons/term/important/>) (CC BY 3.0 (<https://creativecommons.org/licenses/by/3.0/deed.en>))
- Skull and Crossbones by Luis Prado from Noun Project (<https://thenounproject.com/browse/icons/term/skull-and-crossbones/>) (CC BY 3.0 (<https://creativecommons.org/licenses/by/3.0/deed.en>))
- Resources by popcornarts from Noun Project (<https://thenounproject.com/browse/icons/term/resources/>) (CC BY 3.0 (<https://creativecommons.org/licenses/by/3.0/deed.en>))
- Flammable by yogi rista from Noun Project (<https://thenounproject.com/browse/icons/term/flammable/>) (CC BY 3.0 (<https://creativecommons.org/licenses/by/3.0/deed.en>))
- Checkbox by ims.icon from Noun Project (<https://thenounproject.com/browse/icons/term/checkbox/>) (CC BY 3.0 (<https://creativecommons.org/licenses/by/3.0/deed.en>))
- Explosive Materials by Ervin Bolat from Noun Project (<https://thenounproject.com/browse/icons/term/explosive-materials/>) (CC BY 3.0 (<https://creativecommons.org/licenses/by/3.0/deed.en>))
- Work gloves by perilous graphic from Noun Project (<https://thenounproject.com/browse/icons/term/work-gloves/>) (CC BY 3.0 (<https://creativecommons.org/licenses/by/3.0/deed.en>))
- Danger by Alice Design from Noun Project (<https://thenounproject.com/browse/icons/term/danger/>) (CC BY 3.0 (<https://creativecommons.org/licenses/by/3.0/deed.en>))
- Electricity by Alice Design from Noun Project (<https://thenounproject.com/browse/icons/term/electricity/>) (CC BY 3.0 (<https://creativecommons.org/licenses/by/3.0/deed.en>))
- Eye protector by Vectoricons from Noun Project (<https://thenounproject.com/browse/icons/term/eye-protector/>) (CC BY 3.0 (<https://creativecommons.org/licenses/by/3.0/deed.en>))

Land Acknowledgement

Thompson Rivers University (TRU) campuses are situated on the ancestral lands of the Tk'emlúps te Secwépemc and the T'exelc within Secwepemcúl'ecw, the ancestral and unceded territory of the Secwépemc. The rich tapestry of this land also encompasses the territories of the St'át'imc, Nlaka'pamux, Tšilhqot'in, Nuxalk, and Dakelh. Recognizing the deep histories and ongoing presence of these Indigenous peoples, we express gratitude for the wisdom held by this land. TRU is dedicated to fostering an inclusive and respectful environment, valuing education as a shared journey. TRU Open Press, inspired by collaborative learning on this land, upholds open principles and accessible education, nurturing respectful, reciprocal relationships through the shared exchange of knowledge across generations and communities.



TRU Wolves (<https://www.flickr.com/photos/thompsonrivers/52667199689/>) (Thompson Rivers University/Flickr) CC BY-NC-SA 2.0 (<https://creativecommons.org/licenses/by-nc-sa/2.0/>)

If you are using a printed copy, you can scan the QR code with your digital device to go directly to the video: Introducing SkilledTradesBC (<https://www.youtube.com/watch?v=OQgwdP0rNog>)



Starting December 1, 2022, Industry Training Authority was officially renamed to SkilledTradesBC. Hear more in this video from SkilledTradesBC CEO, Shelley Gray, on what this means for the trades industry and British Columbians. Closed captioning and transcripts are available with this video, Introducing Skilled Trades BC (<https://www.youtube.com/watch?v=OQgwdP0rNog>) (2022) on YouTube.



One or more interactive elements has been excluded from this version of the text. You can view them online here: <https://b-handmeasuringtools-bcplumbingapprl1.pressbooks.tru.ca/?p=2446> (<https://b-handmeasuringtools-bcplumbingapprl1.pressbooks.tru.ca/?p=2446>)

AI Use Statement

ChatGPT (<https://chatgpt.com/>) and other (AI) tools may have been used to assist with the development of glossary definitions, support copy editing for grammar, clarity, and readability, and revise some image content. All content was reviewed, revised, and verified by the authors to ensure accuracy and alignment with course and industry standards.

References

- Camosun College. (n.d.). *Line C: Tools and Equipment*. BCcampus. <https://collection.bccampus.ca/resource/BzEe9fcq/>
- SkilledTradesBC. (2025). Plumber program outline (Implementation date: August 18, 2025; Last revised: December 16, 2025) [PDF]. Province of British Columbia. <https://skilledtradesbc.ca/media/2776/download>
- SkilledTradesBC. (2022, December 1). Introducing Skilled Trades BC. YouTube. <https://www.youtube.com/watch?v=OQgwdP0rNog>

Accessibility

The web version of *Block B: Tools and Equipment* (<https://b-handmeasuringtools-bcplumbingappr1.pressbooks.tru.ca/>) has been designed to meet Web Content Accessibility Guidelines 2.0 (<https://www.w3.org/TR/WCAG20/>), level AA. In addition, it follows all guidelines in Appendix A: Checklist for Accessibility (<https://opentextbc.ca/accessibilitytoolkit/back-matter/appendix-checklist-for-accessibility-toolkit/>) of the Accessibility Toolkit – 2nd Edition (<https://opentextbc.ca/accessibilitytoolkit/>).

Includes:

- **Easy navigation.** This resource has a linked table of contents and uses headings in each chapter to make navigation easy.
- **Accessible videos.** All videos in this resource have captions.
- **Accessible images.** All images in this resource that convey information have alternative text. Images that are decorative have empty alternative text.
- **Accessible links.** All links use descriptive link text.

Accessibility Checklist

Element	Requirements	Pass
Headings	Content is organized under headings and subheadings that are used sequentially.	Yes
Images	Images that convey information include alternative text descriptions. These descriptions are provided in the alt text field, in the surrounding text, or linked to as a long description.	Yes
Images	Images and text do not rely on colour to convey information.	Yes
Images	Images that are purely decorative or are already described in the surrounding text contain empty alternative text descriptions. (Descriptive text is unnecessary if the image doesn't convey contextual content information.)	Yes
Tables	Tables include row and/or column headers with the correct scope assigned.	Yes
Tables	Tables include a title or caption.	Yes
Tables	Tables do not have merged or split cells.	Yes
Tables	Tables have adequate cell padding.	Yes
Links	The link text describes the destination of the link.	Yes
Links	Links do not open new windows or tabs. If they do, a textual reference is included in the link text.	Yes
Links	Links to files include the file type in the link text.	Yes
Video	All videos include high-quality (i.e., not machine generated) captions of all speech content and relevant non-speech content.	Yes
Video	All videos with contextual visuals (graphs, charts, etc.) are described audibly in the video.	Yes
H5P	All H5P activities have been tested for accessibility by the H5P team and have passed their testing.	Yes
H5P	All H5P activities that include images, videos, and/or audio content meet the accessibility requirements for those media types.	Yes
Font	Font size is 12 point or higher for body text.	Yes
Font	Font size is 9 point for footnotes or endnotes.	Yes
Font	Font size can be zoomed to 200% in the webbook or eBook formats.	Yes

Known Accessibility Issues and Areas for Improvement

- Images in H5P self-tests lack alt text, attributions, and licenses to avoid revealing answers.
- Some tables may use merged cells, but they have been structured to work properly with screen readers and there may be long descriptions included in each section if readers prefer to see the table data in a bulleted list.
- Youtube videos do not have edited captions.

Adapted from the Accessibility Toolkit – 2nd Edition (<https://opentextbc.ca/accessibilitytoolkit/>) by BCcampus, licensed under CC-BY (<https://creativecommons.org/licenses/by/4.0/>).

Other Formats Available

- In addition to the web version, this book is available in a number of file formats, including PDF. The Print PDF has passed our Accessibility Check.

PART VI

B-6 USE WELDING EQUIPMENT

Plumber Apprenticeship Program – Level 1



Person in Welding Mask While Welding a Metal Bar (<https://www.pexels.com/photo/person-in-welding-mask-while-welding-a-metal-bar-73833/>) (Pixabay/Pexels) Pexels License (<https://www.pexels.com/license/>)

B-6 Use Welding Equipment Introduction

Terminology

The following terms will be used throughout this section. A complete list of terms for this section can be found in the **Glossary**.

- **alternating current (AC):** An electric current that changes direction back and forth many times per second. It is commonly used in homes and buildings. (Section B-6.3)
- **amperes (A):** The unit used to measure electric current, or how much electricity is flowing through a circuit. (Section B-6.3)
- **arc flash:** A painful eye injury caused by exposure to the intense light and radiation from a welding arc. (Section B-6.1)
- **arc length:** The distance between the welding electrode and the metal being welded. (Section B-6.4)
- **arc voltage:** The voltage present in a welding circuit after the arc is struck and the current is flowing. (Section B-6.3)
- **cracking:** Breaks or splits that form in a weld or metal because of stress. (Section B-6.4)
- **current:** The flow of electricity through a circuit, measured in amperes (A). (Section B-6.3)
- **DCEN (direct current electrode negative):** A welding setup where the electrode is connected to the negative side of the power source, causing more heat to be concentrated in the workpiece. (Section B-6.3)
- **DCEP (direct current electrode positive):** A welding setup where the electrode is connected to the positive side of the power source, causing more heat to be concentrated in the electrode. (Section B-6.3)
- **dimensional faults:** Problems with a weld where the size or shape is different from what the design requires. (Section B-6.4)
- **direct current (DC):** An electric current that flows in one direction only, from the negative to the positive side of a circuit. It is commonly produced by batteries and some welding machines. (Section B-6.3)
- **distortion:** A change in the shape of metal caused by heating and cooling during welding. (Section B-6.4)
- **electrode angle:** The direction or tilt of the electrode when it is held during welding. (Section B-6.4)
- **flux:** A coating on a welding electrode that helps protect the molten metal from air and keeps the arc stable during welding. (Section B-6.3)
- **grounded:** Connected safely to the earth so that electrical current can flow away and reduce the risk of electric shock. (Section B-6.1)
- **hot cracking:** Cracks that form in the weld metal while it is still very hot and starting to cool. (Section B-6.4)
- **incomplete penetration:** A welding problem where the weld metal does not fully reach or join the bottom of the joint. (Section B-6.4)
- **inert gas:** A gas that does not react chemically and is used to prevent unwanted reactions such as oxidation or explosions. (Section B-6.1)

- **lack of fusion:** A welding defect where melted metal does not properly join to the metal beside it. (Section B-6.4)
- **lockout:** A safety procedure that ensures equipment is completely shut off and cannot be turned on during maintenance or repair. (Section B-6.1)
- **overlap:** Extra weld metal that spills over the edge of a weld without properly joining to the base metal. (Section B-6.4)
- **polarity:** The direction of electrical flow in a welding circuit, which affects how heat is distributed between the electrode and the workpiece. (Section B-6.3)
- **porosity:** Small holes or bubbles in a weld caused by trapped gas. (Section B-6.4)
- **purging:** The process of removing air or hazardous gases from a space by replacing them with another gas or liquid. (Section B-6.1)
- **residual stress:** Stress that remains inside metal after it has been heated and cooled. (Section B-6.4)
- **respirator:** A protective device worn over the nose and mouth to filter harmful fumes, gases, or particles from the air. (Section B-6.1)
- **self-contained breathing apparatus (SCBA):** A type of respirator that supplies clean air from a tank carried by the user. (Section B-6.1)
- **shielded metal arc welding (SMAW):** A welding process that uses an electric arc between a coated electrode and the metal to join materials. (Section B-6.1)
- **slag inclusion:** Pieces of solid material (slag) that become trapped inside the weld. (Section B-6.4)
- **speed of travel:** How fast the welder moves the electrode along the metal while welding. (Section B-6.4)
- **structural discontinuities:** Flaws or breaks in a weld that weaken the metal. (Section B-6.4)
- **toxic fumes:** Harmful gases or airborne particles produced during welding that can cause illness or injury when inhaled. (Section B-6.1)
- **undercut:** A groove or dip along the edge of a weld that makes the joint weaker. (Section B-6.4)
- **ventilation:** The movement of fresh air through a space to remove harmful fumes, gases, or heat. (Section B-6.1)
- **voltage:** The electrical pressure that pushes current through a circuit, measured in volts (V). (Section B-6.3)
- **volts (V):** The unit used to measure voltage, or the electrical pressure that pushes current through a circuit. (Section B-6.3)

B-6.1 Describe Safety Requirements and Precautions for Arc Welding

Safety Rules for Operating Electric Welding Machines

The greatest electrical hazard for welders comes from electric welding machines. For this reason, every time you work with these machines, you must follow all the standard safety precautions.

All switches must be clearly marked, all tools and equipment must be properly **grounded**, and metal ladders must be nowhere near any source of electrical power.

Maintenance of Equipment

The welder who is about to use a machine is responsible for ensuring that the welding machine is in a safe operating condition. The wiring, switches, controls, and cables must all be thoroughly checked before use, and preventive maintenance (such as internal cleaning and lubrication) must be carried out at regular intervals.

In most welding shops, the power supply for arc welding equipment is 230 V, 460 V, or 575 V. These are high voltages that can easily deliver severe or fatal shocks. When performing any internal preventive maintenance work on electric welding equipment, observe the following rules:

1. All troubleshooting and maintenance of welding machines must be done only on dead circuits. Make sure that the main power supply disconnect switch is open and locked out.
2. All work on main power lines, junction boxes, and fuses may only be carried out by a qualified electrician, in accordance with the requirements of the Canadian Electrical Code. As a welder, your maintenance responsibilities end with your welding machine.

Power Circuit Ground

When you connect an electric welding machine to its main power source, it is extremely important to ensure the main power circuit is properly grounded. Without proper grounding, any stray current that develops could give you or another welder a severe or fatal shock. If you have one hand on an inadequately grounded machine in which a current is flowing and accidentally touch a grounded metal object such as a switch box, you become part of the electric circuit. The resulting electric shock could be fatal.

Welding Cables

The cables on a welding machine should be checked every time the machine is used. You should never use electric

current that exceeds the rated capacity of the welding cables on your machine. This is uneconomical but, more importantly, it causes overheating and rapid deterioration of the insulation. Faulty insulation is a hazard. If exposed sections of cable come in contact with any grounded metal object in the welding circuit, they could create an arc, which could in turn ignite any flammable materials in the area.

Make inspection of the cables a standard part of your inspection of welding equipment prior to use. If the cables are in good condition, you can use them. In other cases:

1. Be sure the main power source is disconnected and locked out.
2. If there are surface cracks in the insulation, repair them with electrical tape before starting the machine.
3. If there are breaks in the insulation that expose any wire, do not try to repair it. Replace the cable with one that is in good condition.

Fire Prevention

The electrical welding processes such as **Shielded Metal Arc Welding (SMAW)** pose as great a fire hazard as the oxy-fuel welding processes. Observe the following points:

1. **Housekeeping:** Ensure that your workplace is as free as possible of combustible materials before you begin to weld.
2. If flammable materials cannot be removed from the work area, be sure they are protected adequately from sparks and slag before you start to weld. Use welding blankets.
3. Do not weld anywhere near containers of flammable liquids.
4. Know the locations and type of fire extinguishers in your immediate work area and their operating procedures.

Eye Protection for the Electrical Welding Processes

When you weld using an electrical process such as SMAW, you must take extreme care to protect your eyes. The infrared and ultraviolet rays that are the products of the arc welding process can cause serious and sometimes permanent injury to your eyes.

The burn that results from the exposure of inadequately protected eyes to the welding arc is known as **arc flash**. Even a one-second exposure at a distance of 0.5 m (20 in.) is enough to burn the eyes.

Never look at an arc with the naked eye. If you receive an arc flash, immediately report it to your instructor. WCB stipulates a minimum distance of 12 m (40') between an arc and the naked eye.

Helmets

To protect your eyes, face and neck during arc welding, you must wear a helmet or use a hand shield equipped with a dark filter lens. These lenses come in a range of different shades, each with a different number. Your choice of lens depends on the level of current you are using, since this determines the intensity of the arc. Table 1 lists lens shade

numbers recommended for different current settings. These are suggestions only. The sensitivity of your eyes may require that you use a darker lens.

Table 1: Recommended Lens Shades for Level of Current

Level of Current	Lens Shade
Below 30A	No. 6
30-70 A	No. 9
70-200 A	No. 10
200-300 A	No. 11
300-400 A	No. 12
Over 400 A	No. 13

If your eyesight requires them, use wide vision or clear magnifying lenses. These special lenses fit behind your filter lens.

Always check the shaded lens in your face shield or helmet before you start to weld to make sure it is not cracked or broken. If it is cracked or chipped, replace it immediately.

If you are in a shop where arc welding is being done, wear flash goggles as protection from arc flash. Similarly, if you are welding near another welder, wear flash goggles in addition to a helmet or face shield to avoid the risk of arc flash anytime your helmet is raised.

Arc Burn

The infrared and ultraviolet radiation that occurs with arc welding can cause damage to improperly protected eyes and cause severe burns to your body. For this reason, you must wear the proper protective clothing and equipment when using the SMAW process.

The amount of protective clothing you require depends on how much welding you are doing and on the welding positions you use. At the very least, when you are performing SMAW, all parts of your body must be covered. Use a flame-resistant leather jacket, aprons and sleeves and, for some jobs, leggings and anklets. Your standard protective clothing for arc welding must also include a peaked cap, leather gloves and safety boots.

For arc welding of any kind, your clothing should be dark to reduce the reflection of the arc. If you suffer burns as a result of arc welding, see your doctor at once.

Hearing Protection

In a welding shop or on a construction site, the noise from weld cleaning, chipping, grinding and hammering, as well as from welding machines and power tools, can cause hearing damage.

The signs of hearing damage can be a constant ringing in the ears, hearing loss, temporary deafness and, in extreme cases, permanent deafness. Hearing loss may occur so gradually that you may not be aware it is happening.

You need protection from both steady state and impact noise. In any shop or on any job site where the general or steady state noise level exceeds 90 decibels or where the impact noise levels are in excess of the maximum indicated by the

Regulation, you should wear Canadian Standards Association (CSA) approved ear plugs or earmuffs. Hearing protection devices are rated A, B and C to indicate the noise levels for which they are effective (Table 2).

Table 2: Noise Levels and Appropriate Hearing Protection

Steady State Noise for 8 hrs. (dBA)	Minimum CSA Class of Hearing Protector
85-95	C
96-105	B
106-115	A
Over-115	A muff and B plug
Impact Noise	A
	CSA Standard Z94.2-1974

Hearing protection devices can be rubberized earplugs that are inserted into the cavity of the ear or earmuffs, which fit over the ear (Figure 3). When selecting hearing protection devices, make sure that they are CSA approved. Earplugs should be clean, pliable and well-fitting, and earmuffs should be adjusted to fit snugly over your ears.



Figure 3 Rubberized earplugs and earmuffs (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Neither headphones used with music systems nor cotton stuffed into your ears, will give you adequate protection from noise.

Fire and Explosion Prevention

Optional Resource: Real-World Incident

You may be interested in this real-world example from WorkSafeBC (2010): Explosion during welding operation (<https://www.worksafebc.com/en/resources/health-safety/incident-investigation-report-summaries/explosion-during-welding-operation>)

A worker was welding on an aluminum boat when a welding arc ignited undetected flammable vapours, causing an explosion that threw the worker several metres and damaged the structure.

This incident highlights the importance of proper hazard assessment, ventilation, and testing for flammable vapours before performing hot work.

Flammable Hazards

The flammable materials include acetylene, naphtha, turpentine and gasoline. When concentrations of fumes from flammable liquids are present, there is a great risk of these fumes being ignited by contact with an open flame or spark.

The symbol shown in Figure 4 should be located on all containers used for flammable materials.



Figure 4 Flammable materials symbol

Flying Sparks

One of the major fire hazards is flying sparks. Unlike flame, the effects of which are confined to the immediate area of the work, sparks travel fast and far. A spark can travel over 9 m (30') and hold its heat several seconds after landing. Sparks can lodge themselves in cracks and start smouldering fires that may not burst into flames until after you have left the area.

Never weld where sparks may come into contact with flammable vapours, liquids or materials. Sweep floors clean and, if they are wood, wet them down before you light the torch. If there is a possibility that sparks might pass through cracks in walls or floors, cover the holes or move the work.

If you can move your work, set it up in an area that is free from flammable materials. If you cannot move the work, move the flammable material to another area. If neither the work nor the flammable material can be moved, use sheet metal or fireproof guards to keep sparks close within the area of your work. Set pans of water or sand where they will catch dripping slag and pieces of hot metal that might fall.

After you set up the sheet metal or asbestos guards, have someone check to see if sparks are flying over or around them. When you change the direction of flame toward the work, the direction and range of sparks may change. Make periodic checks to see that you are providing enough protection in the right places.

Fire Watchers

Welding and cutting operations should be carried out in areas free from combustible materials. When work must be done near flammable material, the National Fire Protection Association (NFPA) (<https://www.nfpa.org/>) states that you must have a designated fire watcher.

The NFPA also requires the following:

- Fire watchers shall have fire extinguishing equipment readily available and be trained in its use, including practice on test fires.
- Fire watchers shall be familiar with facilities and procedures for sounding an alarm in the event of a fire.
- Fire watchers shall watch for fires in all exposed areas and try to extinguish them only if the fire is obviously within the capacity of the equipment available; if it is not, the fire watcher shall sound the alarm immediately.
- A fire watch shall be maintained for AT LEAST HALF AN HOUR after completion of cutting or welding operations to detect and extinguish possible smouldering fires.

Compressed Gas Cylinders

The most common sources of explosive hazards in welding shops are the compressed acetylene and oxygen cylinders used in the oxy-fuel processes. The contents of these cylinders must always be identified on the cylinder. The cylinders must be handled correctly, in accordance with regulations and they must, if possible, be stored in an upright position.

The symbol indicating an explosive hazard is shown in Figure 5 and should be located on all containers or materials that are explosive.



Figure 5 Explosive hazard symbol

Containers That Previously Held Flammable Material

If containers have previously held flammable materials, welding or cutting them could cause an explosion. Certain preparatory methods of cleaning and **purging** must be used before welding or cutting is attempted.

One method for removing flammable materials is to steam or boil the container in a caustic solution, a method that is usually too slow, costly and uncertain for commercial work. It may entail days or weeks of processing since lap seams, laminations in the plate of the vessel, or open roots or welds made from both sides may contain pockets of combustibles that are difficult and time consuming to remove.

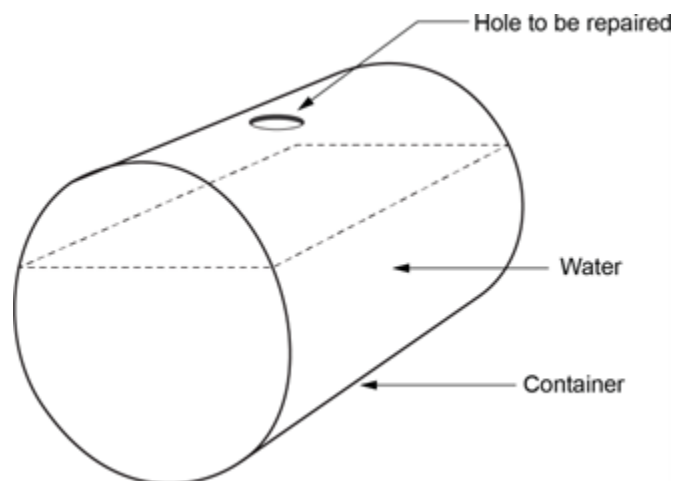


Figure 6 Displacement of air with water (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

A second and less expensive method is to fill the container with water. The water displaces the air in the container so

that an explosion cannot be supported. The container is filled to overflowing, then water is removed to a level just below the hole to be repaired (Figure 6). The air in the container is then checked with a gas detector to ensure that no explosive vapours remain.

There must be a vent hole in the container that is large enough to allow the vapours to escape. Sometimes it will be impossible to leave the vent open, particularly for containers that are positioned on their side (Figure 7). In cases such as these, you have to make sure the hole to be welded is large enough to act as a vent.

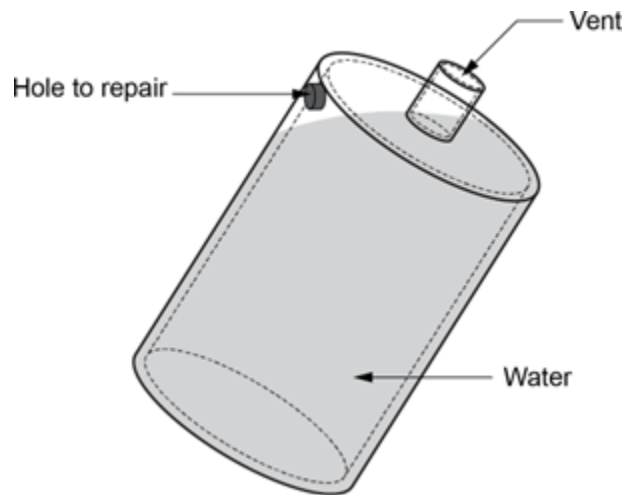


Figure 7 Water displacing air (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Purging is a third method to rid containers of flammable gases. The container is completely filled with an **inert gas** such as nitrogen, argon or helium, which does not explode. These gases displace the air or oxygen which is explosive.

When using this method, you must know whether your purging gas is heavier or lighter than air. If the purging gas is argon, which is heavier than air, you must fill the container from the bottom (Figure 8).

If the purging gas is nitrogen or helium, which is lighter than air, you must fill the container from the top. A vent must be left open to allow the air to escape. Enough purging gas must be used to remove all the air. The procedure should be done in an area free of drafts or wind that would tend to disperse the purging gas.

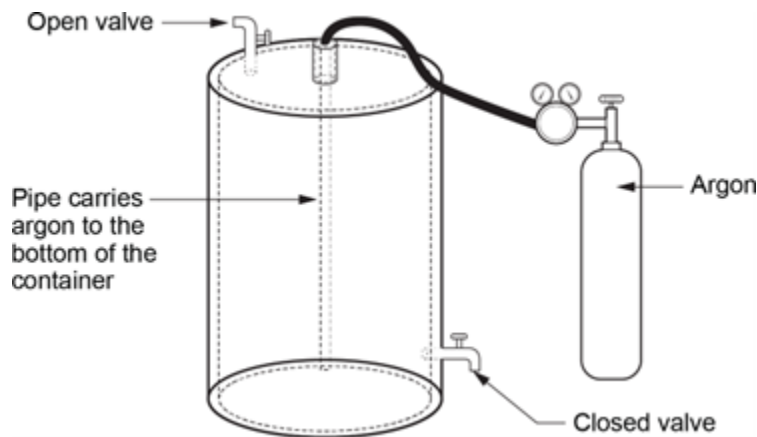


Figure 8 Purging with inert gases heavier than air (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

This method is expensive for ordinary use, but for jobs such as the purging of acetylene manifold systems, this is the best suited method since no moisture or heat is involved.

Steaming is the fourth and most common method of making containers safe for welding or cutting. This process consists of opening all vents and blowing in live steam under pressure until all dangerous traces of combustibles are gone. The container must be welded while it is still hot and full of steam. After cooling begins and air has been drawn into the container, it is no longer safe to weld or flame cut.

The length of steaming time depends on the size and pressure of the steam line, the size of the container and the container's previous contents. As an extra safety precaution, the container can be filled with inert gas after it has been steamed clean.

Before you begin to weld or flame cut after cleaning or purging the container, you should always test the container using an explosive vapour detector.



Figure 9 Toxic hazard symbol

Toxic hazards include the fumes or airborne particles present during welding or produced as a byproduct of welding. The symbol used on containers of toxic materials is shown in Figure 9.

The toxic materials that are most commonly associated with the welding process are in Table 3.

Table 3: Hazardous Substances and Health Effects Associated with Welding

Substance	Common Source or Use	Health Effects
Asbestos	Used as insulation for pipes.	Highly toxic. Exposure can cause asbestosis and lung cancer .
Beryllium	Used in plating.	Inhalation of fumes can cause coughing, lung inflammation, breathing difficulty, fatigue, weight loss, and heart disease after long exposure.
Cadmium	Alloyed with silver or brass; used in silver brazing alloys, plating, or paint coating on some electrodes. Cadmium-coated metals may resemble galvanized metals.	Exposure to fumes can cause breathing difficulty, weakness, general illness, lack of appetite, nausea, metallic taste, chest pain, coughing, decreased urine output, and possibly death from respiratory failure.
Carbon dioxide	Used as a shielding gas in some welding processes.	In confined areas, excessive amounts can cause suffocation. May also break down into carbon monoxide in poorly ventilated areas.
Carbon monoxide	Byproduct of welding with shielding gas; also emitted by gasoline-powered welding machines.	Colourless and odourless gas. Early symptoms include headache, dizziness, and mental dullness. Severe exposure can cause unconsciousness and death by suffocation.
Carbon tetrachlorine and trichloroethylene	Commonly used as degreasing agents.	Exposure can cause abdominal pain, nausea, vomiting, dizziness, confusion, irregular pulse, falling blood pressure, jaundice, and reduced urine output.
Chlorine	Used in wood pulp industries and water or sewage treatment plants.	Causes burning in eyes, nose, and throat. Higher exposure may cause nausea, choking, chest pain, lung fluid buildup, and suffocation. Contact with liquid or vapour may cause burns.
Cyanide	Used for hardening some steels.	Can cause effects ranging from mild allergic reactions to severe poisoning and death.
Fluoride	Found in fluxes used when welding or brazing stainless steel, nickel, aluminum, and magnesium.	Exposure can cause coughing, bronchitis, breathing difficulty, and fluorosis, which changes bone structure.
Lead	Found in pipes, paint, electrodes, solders, and sheet materials.	Inhalation causes lead accumulation in organs and bones. Symptoms include metallic taste, nausea, vomiting, gum discoloration, and long-term nervous system damage.
Manganese	Used as a deoxidizer and strengthener in steel.	Fumes can cause coughing, bronchitis, fever, headaches, muscle pain, chills, dermatitis, and liver enlargement.
Mercury	Found in plating and some paints.	Exposure can cause abdominal pain, excessive salivation, metallic taste, diarrhea, coughing, and reduced urine output.
Nitrous gases	Produced by the arc or flame during welding processes.	Can cause breathing difficulty and rapid fluid buildup in the lungs several hours after exposure.
Phosgene	Produced when carbon tetrachloride or trichloroethylene is heated or exposed to ultraviolet radiation.	Causes throat irritation, chest tightness, breathing difficulty, lung inflammation, and possibly death from respiratory failure.
Ozone	Produced by welding arcs and ultraviolet radiation during electrical welding processes.	Causes irritation of the eyes, nose, and throat.
Teflon	Found in pipe linings and tap-valve seals.	When heated above 390 °C (728 °F), it produces highly toxic gases that cause weakness, numbness, throat pain, and breathing difficulty.
Zinc	Found in galvanized plating and brass; zinc chloride used as flux.	Exposure to fumes can cause <i>metal fume fever</i> , with symptoms such as headache, chills, fever, chest tightness, and stomach upset.

Note. Welding fumes from metals such as aluminum, chromium, copper, iron, nickel, titanium, and vanadium are generally not toxic at typical welding concentrations but may become harmful at higher levels.

Ventilation

Adequate **ventilation** must be provided when **toxic fumes** from materials such as lead, zinc, cadmium, beryllium and Teflon are present in harmful concentrations.

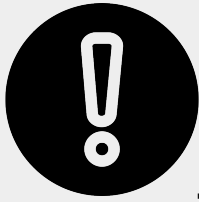
Ensure that booths or welding screens do not hinder air movement needed for ventilation. Welding booths require a minimum air movement of 30 metres (100 linear feet) per minute.

Although many gases can be identified by their smell, you can never totally rely on your sense of smell. Deadly hydrogen sulphide, for example, is easily recognized by its odour of rotten eggs at low concentrations, but in higher concentrations it becomes odourless. The only reliable method of detecting dangerous gases is to use special detection equipment. These detectors test the air for the presence of explosive vapours and are commonly called explosimeters. Other types of detectors are designed to test the air for the presence of toxic gases such as chlorine or hydrogen sulphide.

Working in Confined Areas

Welding or cutting in confined areas such as tanks, boilers, pressure vessels, vaults and holds of ships requires special attention to safety. The following special precautions are necessary for working in confined areas:

- Check air upon entering.
- Ensure adequate ventilation, especially when using low-hydrogen or stainless-steel electrodes.
- Never use oxygen.
- Keep cylinders outside the confined area.
- Have a helper outside with a lifeline, if necessary.
- Pay special attention to leaks.
- Light your welding or cutting torches outside and have them handed in, if possible.
- Never take welding or cutting torches inside until pressures have been regulated.
- Do not keep torches inside the confined area for any length of time.
- Check for harmful concentrations of ozone during inert gas welding.
- Check for explosive vapours that may be present or produced by the welding.
- Wear appropriate respiratory protective equipment, if necessary.
- Never enter a confined area to rescue personnel overcome by fumes or lack of oxygen without summoning help first; make sure you wear the appropriate breathing apparatus if you do enter.



WorkSafeBC Note: Welding Fumes

Welding fumes can cause serious short- and long-term health effects. Always ensure proper ventilation and follow exposure control procedures.

You may be interested:

- Ask an officer: Controlling the risk of welding fume exposures (<https://www.worksafebc.com/en/about-us/news-events/campaigns/2024/March/ask-an-officer-controlling-risk-welding-fume-exposures>) (WorkSafeBC, 2024)
- Controlling Exposure Risks from Welding and Cutting Processes (<https://www.worksafebc.com/en/resources/health-safety/books-guides/controlling-exposure-risks-welding-cutting-processes>) (WorkSafeBC, 2024b)

Respiratory Protective Equipment

Respirators can provide protection against toxic fumes. There are three types of respirators that you may be required to use. The in-line respirator (Figure 10) draws air from a line (fresh air source). A filter in the supply line removes pipe scale, water, oil, mist and noxious vapours. A pressure-reducing valve prevents the pressure of the air from exceeding 170 kPa (25 psi).

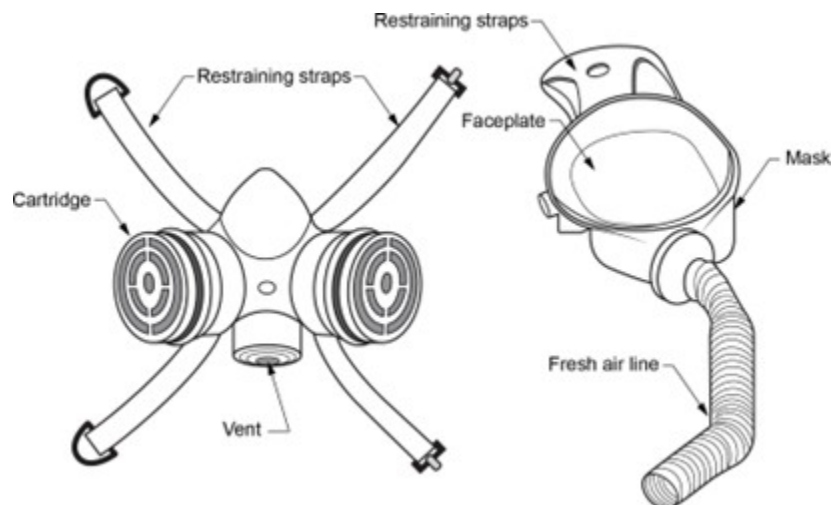


Figure 10 Cartridge respirator and air-line respirator (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Air-line respirators must be worn during welding or flame cutting operations done either in the presence of toxic fumes

or in confined spaces where oxygen levels in the air are inadequate. Typical operations of this kind include the repair of leaks in pipes or tanks containing toxic chemicals or repair work to the inside of large tanks or vessels.

A second type of respirator used for similar operations is the **self-contained breathing apparatus (SCBA)**. Rather than using air from a fresh outside source, this unit draws air from an oxygen cylinder strapped to the worker's back.

The **cartridge-type respirator** (Figure 10) is used only for emergency escape. The cartridge in the respirator is able to neutralize the toxic gases for a very short time, allowing you just enough time to get out of the area. In work settings where there is a danger of toxic gas leaks, workers carry this type of respirator on their person at all times. Cartridges are available for different gases, and most types of cartridge provide protection against a range of gases.



Figure 11 OV/P100 cartridge-type respirator (Jcallah/Wikimedia Commons) CC BY-SA 4.0 (<https://creativecommons.org/licenses/by-sa/4.0>)

Employees required to wear respirators should keep their equipment clean and sterilized. When not in use, the equipment should be stored in closed containers. The equipment should be inspected regularly for wear or damage. A program should be set up to control the selection, fitting, testing and maintenance of the equipment.



Self-Test B-6.1: Describe Safety Requirements and Precautions for Arc Welding

Complete Self-Test 6.1 and check your answers.

If you are using a printed copy, please find Self-Test A-6.1 and Answer Key in the Appendix at the end. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.



An interactive H5P element has been excluded from this version of the text. You can view it online here:
<https://b-handmeasuringtools-bcplumbingapprl1.pressbooks.tru.ca/?p=3037#h5p-18> (<https://b-handmeasuringtools-bcplumbingapprl1.pressbooks.tru.ca/?p=3037#h5p-18>)

References

BC Industry Training Authority. (2019). *Piping trades apprenticeship program: Use Tools and Equipment—Level 1 harmonized* [Binder]. Crown Publications, Queen's Printer for British Columbia. https://www.crownpub.bc.ca/Product/Details/7960000261_S

- Sprinkler Fitter (Harmonized 2018)
- Plumber: Competency B-7 Use Welding Equipment
- Steamfitter: Competency B-5 Use Welding Equipment

- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-5: Use welding equipment (Steamfitter)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-5: Use cutting, brazing and soldering equipment (Plumber)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-6: Use oxy-fuel cutting equipment (Plumber)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-6: Use soldering and brazing equipment (Steamfitter)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-7: Use oxy-fuel equipment (Steamfitter)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-7: Use welding equipment (Plumber)*. Crown Publications, Queen's Printer for British Columbia.
- WorkSafeBC. (2024a, March 13). Ask an officer: Controlling the risk of welding fume exposures. <https://www.worksafebc.com/en/about-us/news-events/campaigns/2024/March/ask-an-officer-controlling-risk-welding-fume-exposures>
- WorkSafeBC. (2024b). Controlling exposure risks from welding and cutting processes. <https://www.worksafebc.com/en/resources/health-safety/books-guides/controlling-exposure-risks-from-welding-and-cutting-processes>

Media Attributions

All figures are sourced from Industry Training Authority (2019) and/or Camosun College (2019) and are used under the Creative Commons Attribution 4.0 (CC BY 4.0 (<https://creativecommons.org/licenses/by/4.0/>)) licence unless otherwise noted. Images copyrighted by the BC Industry Training Authority are licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 (CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)) licence.

- **WHMIS pictograms** (<https://www.ccohs.ca/WHMISpictograms.html>), **pictogram poster** (<https://www.ccohs.ca/products/posters/WHMIS-pictograms>) and **WHMIS labels** (<https://www.ccohs.ca/products/posters/WHMIS-labels>) posters downloaded from the CCOHS (2024) WHMIS Pictograms Kit (<https://www.ccohs.ca/WHMISpictograms.html>) (downloads) page are used with permission and under the CCOHS terms for educational purposes.
- **Figure 11** P100 ovm respirator (https://commons.wikimedia.org/wiki/File:P100_ovm_respirator.jpg), by Jcallah on Wikimedia Commons is used under a CC BY-SA 4.0 (<https://creativecommons.org/licenses/by-sa/4.0/>) license.

B-6.2 Identify Types of Welds, Positions, Joints and Symbols

Identify Weld Types

There are five types of welds used in non-pressure welding (Figure 1):

- Bead weld
- Tack weld
- Fillet weld
- Groove weld
- Plug and slot weld

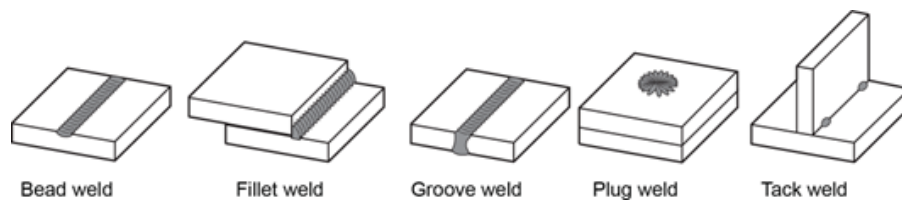


Figure 1 Weld types for non-pressure welding (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Bead Welds

Bead welds are single-pass deposits of weld material used to build up the surface of metal or to replace metal on worn surfaces. Bead welds used for this application are commonly called **hardsurfacing or hardfacing**.

Tack Welds

Tack welds are a series of short welds used to hold the joint assembly in place during the *fit-up procedure* (Figure 2). Each tack weld is a short (sometimes temporary) weld approximately 13 mm ($\frac{1}{2}$ ") in length. Tack welds are usually deposited at both ends of the joint and at approximately equal intervals along the length of the joint.

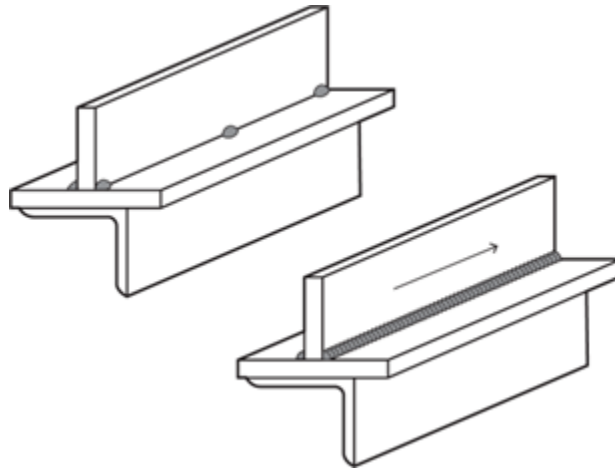


Figure 2 Tack welds (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

On tee joints, tack welds are often used along the opposite side of the weld to prevent the upright plate from leaning toward the weld (Figure 3).

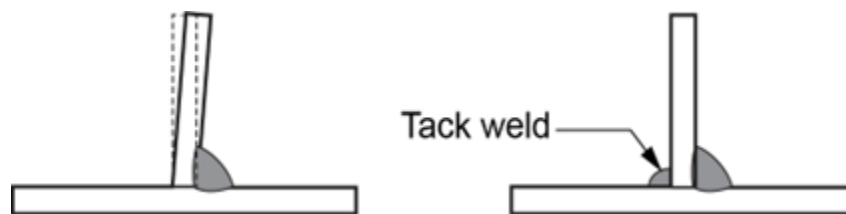


Figure 3 Tack weld (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Fillet Welds

Fillet welds are used extensively on lap, tee, and corner joints where they join two pieces of metal that are usually at right angles (90°) to each other. A fillet weld consists of one or more beads or layers that are roughly triangular in cross-section. The features of a typical fillet weld on a tee joint are shown in Figure 4.

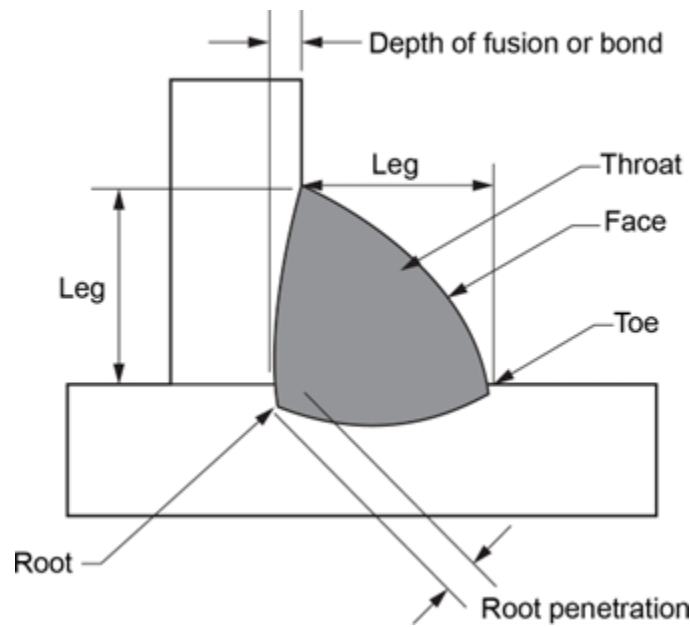


Figure 4 Ideal fillet weld (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

The ideal fillet weld is characterized by:

- Joint faces at right angles (90°)
- Face that is flat or slightly convex
- Toes that merge smoothly with the surface of the joint members
- Legs of equal length

In many cases, fillet welds are more economical than groove welds, in that they are easier to assemble and require less edge preparation. They generally require more weld material and are less able to withstand high stress loads.

Fillet welds are not considered capable of carrying stress loads unless their length is at least four times the size of the weld. Stress-carrying fillet welds connecting material up to 25 mm (1") thick should not be less than 10 mm ($\frac{3}{8}$ in) in size.

Groove Welds

Groove welds fill in the gap or groove between two pieces of metal. Groove welds are most commonly used on butt joints, although the weld on an open corner joint or on specially prepared lap and tee joints can sometimes be considered a groove weld.

Groove welds consist of a root bead, a hot pass, fill passes and a cap (Figure 5). The number of passes will vary, depending on the thickness of the material. On thinner metal, the hot pass and fill pass can be combined into one pass and, in some cases, a single pass is adequate for the entire weld.

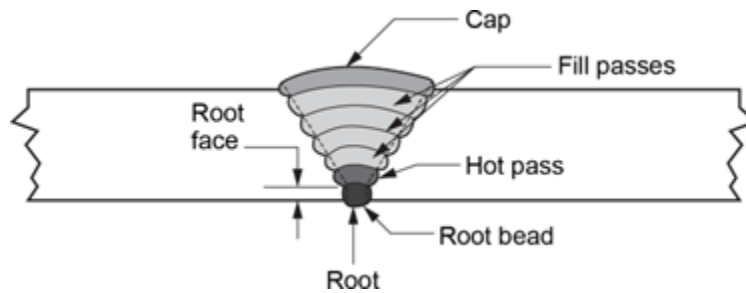


Figure 5 Groove weld (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

The significant dimensions of groove welds are shown in Figure 6. These include the **root opening**, the **root face (or landing)**, the included angle, the thickness and the throat. On bevelled joints, the bevel angle is important and, on joints with a J preparation, the **root radius** is significant.

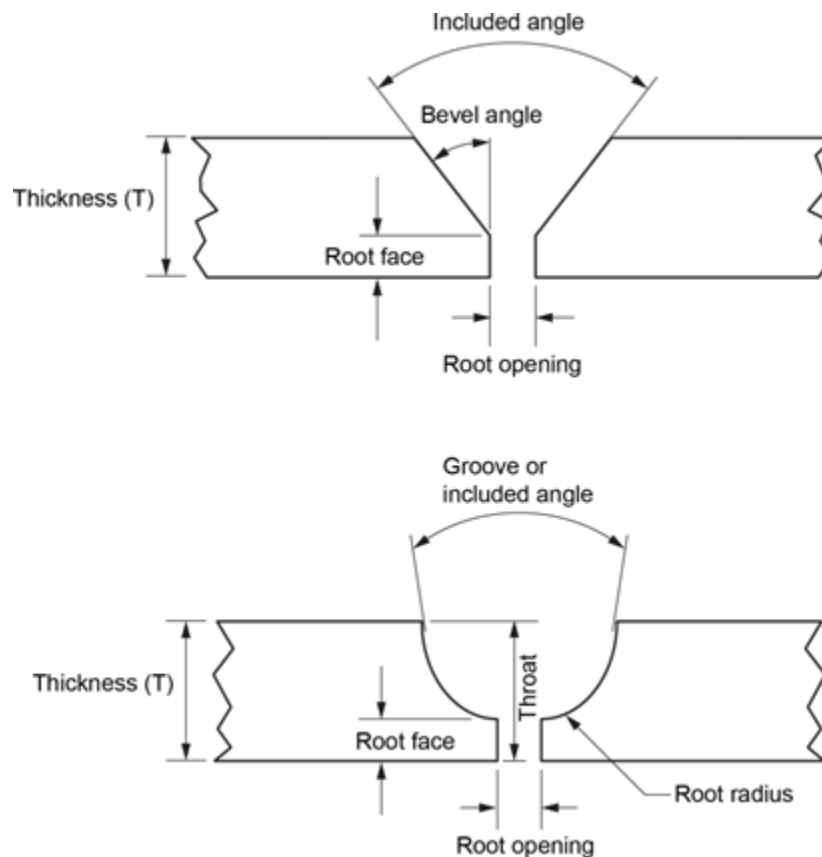


Figure 6 Groove weld dimensions (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

The size of the root opening, the root face, the included angle, and the root radius all have bearing on the amount of weld material required and on the depth of penetration. For example, too large a root opening, face or included angle will result in excessive penetration and the deposition of unnecessary weld metal, while dimensions that are too narrow will make full penetration extremely difficult, if not impossible. If the root radius on a U-joint is too great, an excessive amount of weld material will be deposited and the possibility of uncontrollable distortion increases.

The selected dimensions for these dimensions will depend on the material thickness, electrode size and the welding process.

Groove Weld Size and Profile

The size of **groove welds** is determined by the depth of weld penetration in the groove or gap between the two pieces. In Figure 7, the weld size in A (where penetration is complete) is the same as the thickness of the plate. Where penetration is incomplete, as in B, the weld size is the depth of the penetration. In C (where the plates differ in thickness and there is complete penetration), the weld size is the thickness of the thinner plate.

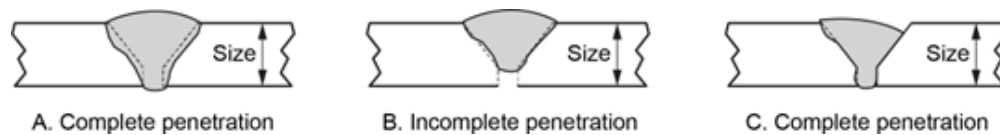


Figure 7 Groove weld sizes (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Metal deposited above the surface of the plate is called reinforcement. Profiles of groove welds show the amount of reinforcement at the centre of the weld bead (Figure 8). This reinforcement must not exceed 3 mm ($\frac{1}{8}$ ”) as excessive reinforcement is uneconomical and contributes nothing to the strength of the weld. It decreases the working strength of the joint because stresses concentrate at the toe of the weld.

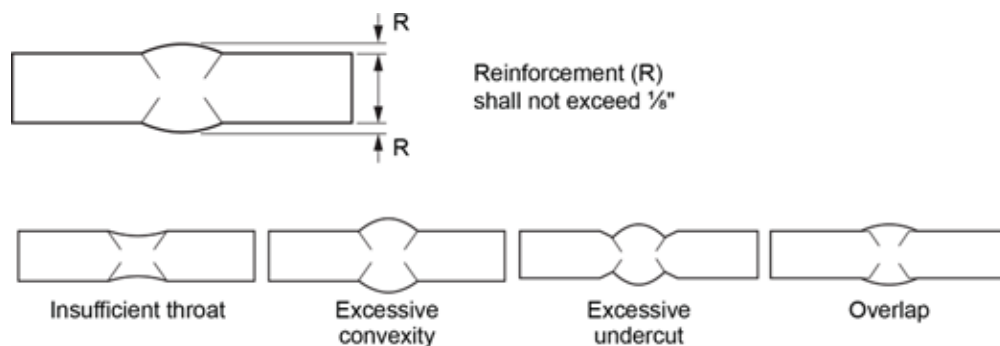


Figure 8 Groove weld profiles (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Reinforcement may be removed by gouging or it must be built up uniformly from the surface of the parent metal to the maximum 3 mm ($\frac{1}{8}$ ”) at the centre of the weld. There must be no valley or groove along the edge or in the centre of the weld.

The width of a groove weld should not extend more than 3 mm ($\frac{1}{8}$ ") beyond the shoulder or edge of the joint on either side. Extra deposit beyond this is uneconomical because there is no corresponding increase in joint strength.



If you're unsure which weld to use, start by identifying the **joint type** first.

Five Basic Joint Types

There are five basic **weld joints** used in welding (Figures 9 and 10). Within these five, however, are many variations and the selection of a particular joint or variation is based on four important factors:

- The load applied to the weld (for example, compression, torsion, bending, or fatigue)
- The way the load is applied (for example, sudden, variable, or steady)
- The thickness of the base metal
- The cost of the joint preparation and welding time

The five basic weld joints are defined below:

Butt Joint: A joint that joins two pieces of metal in the same plane.

Corner Joint: A joint that joins two pieces of metal at right angles, formed at the ends of both pieces in an L shape.

Edge Joint: A joint that joins two pieces of metal that are turned up at the edges; also known as a flange joint.

Lap Joint: A joint that joins two pieces of metal that overlap one another.

Tee Joint: A joint that joins two pieces of metal at right angles, forming a "T" shape.

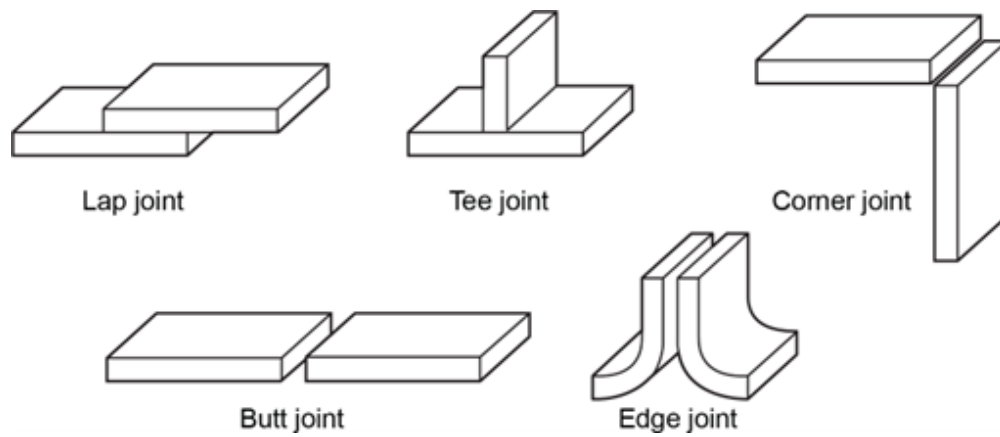


Figure 9 Five basic joints (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

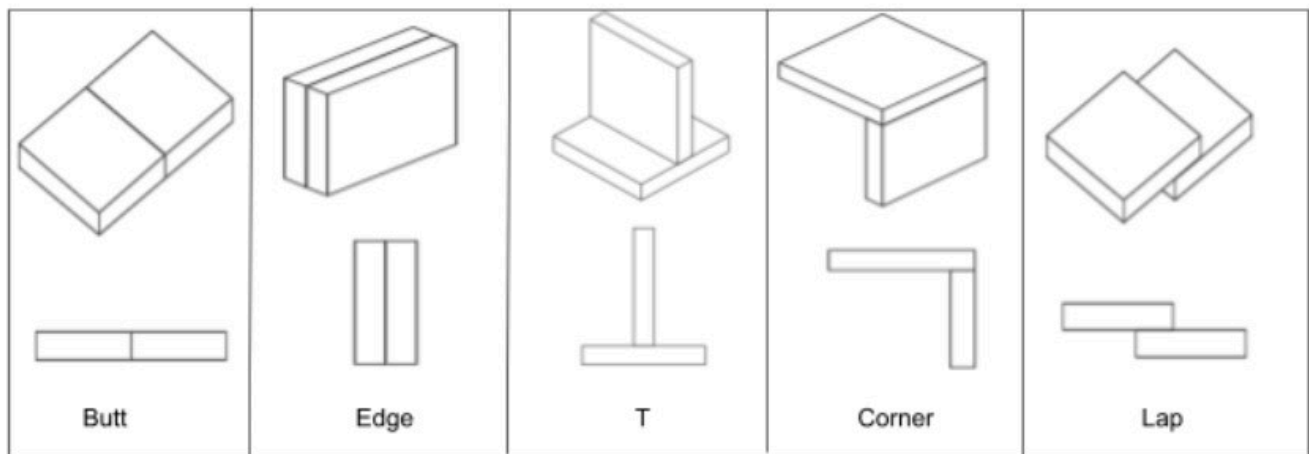


Figure 10 Basic joint types (Cameron Kjeldgaard/OpenWashington) CC BY 4.0 (<http://creativecommons.org/licenses/by/4.0>)

Variations in Joint Design

Variations in the five basic designs are a result of the different preparations that can be applied to the edges of the joint. Edge preparation is necessary on thicker material to ensure full penetration of the joint.

Tee Joints

The **square tee joint** requires no edge preparation and is widely used because it is relatively inexpensive and easy to fit. On thicker material, the edges may be prepared with a single bevel, double bevel, single J or double J (Figure 11).

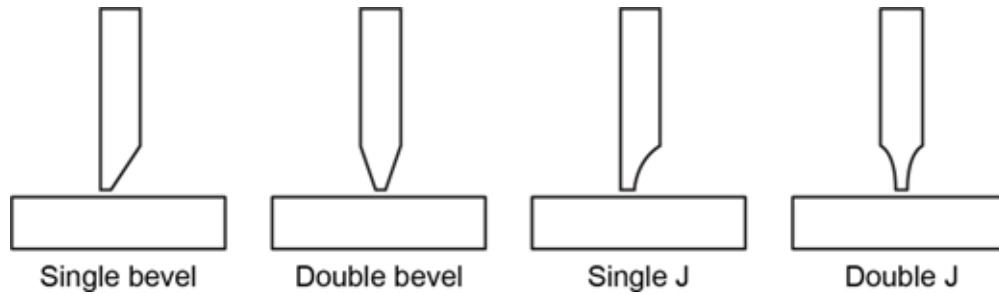


Figure 11 Edge preparations for tee joints (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Tee joints that are welded on only one side (single-welded) are satisfactory for only light static loads. For heavy or fluctuating loads, tee joints need to be welded on both sides (double-welded) to increase their strength.

Tee joints are relatively easy to design and they provide maximum access for welding, however, there is a high possibility of distortion. An additional drawback is the expense of tee joints in terms of the weld material, especially on larger tee joints and on joints that need to be welded from both sides.

Lap Joints

Lap joints require little or no edge preparation. On thicker material, a single bevel is all that is usually required. Lap joints are often selected for welds between two materials that have different thickness.

For welds that do not require great strength, a single lap joint may be selected to provide a “tight” joint. However, single lap joints must not be used for welds that will be subjected to fluctuating, bending or twisting loads. For these types of loads, the joint can be welded from both sides, or a double lap joint can be selected (Figure 12).

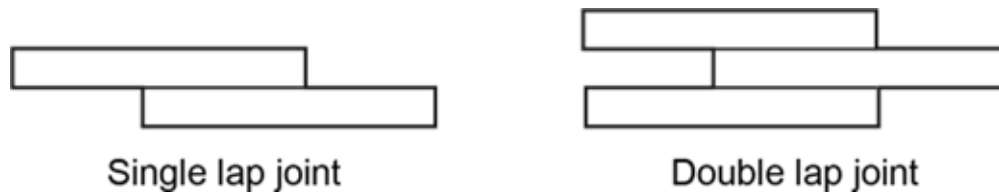


Figure 12 Variations on lap joints (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Lap joints have two significant drawbacks. As with tee joints, the material requirements are high, so maximum tensile strength can only be achieved when the overlap is five times the thickness of the thinner member. Also, under stress loading, the joint tends to lose its strength.

Corner Joints

There are two types of **corner joints**, the open corner and the closed corner (Figure 13).

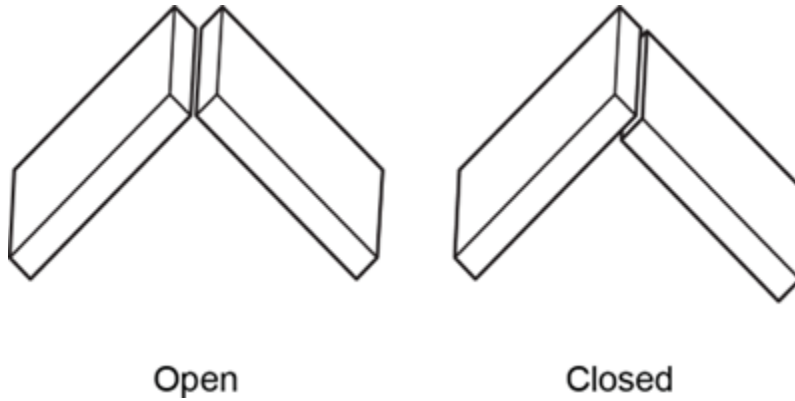


Figure 13 Types of corner joints (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

The open corner joint is more frequently used than the closed corner. Penetration is usually excellent, resulting in a full strength weld. With the closed corner, penetration is impossible on all but light-gauge sheet metal. On thicker material, edge preparation is required (Figure 14). In addition to the edge preparation, a small opening is often left between the two pieces in order to ensure full penetration.

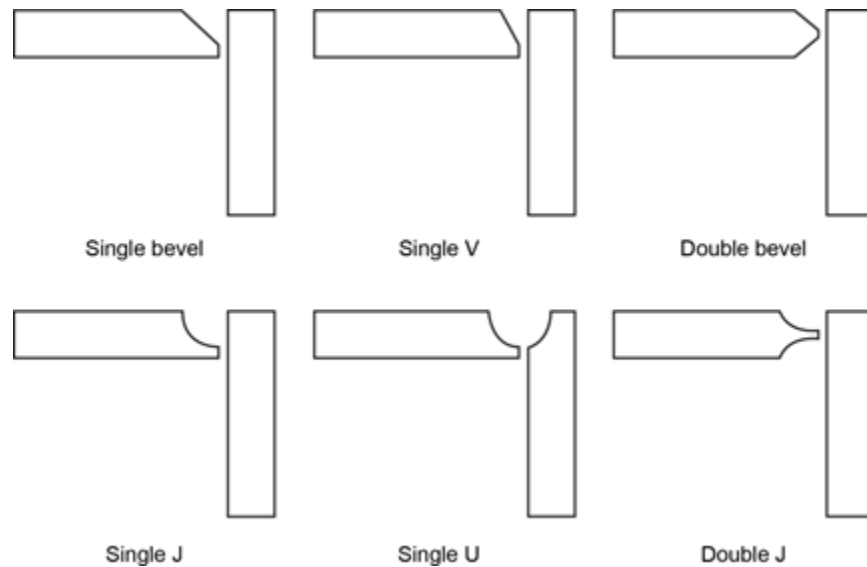


Figure 14 Edge preparation for corner joints (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Although square corner joints are relatively easy to prepare and assemble, the variations using the bevel, the J and the U preparations require more skill and time to accurately fit the joint.

Corner joints are not satisfactory for heavy stress loading, particularly if welded from only one side. They are not normally used in construction, especially where the tension from bending is concentrated at the root of the weld. For some applications, corner joints may also be welded from the inside to increase their strength, a procedure that significantly increases the cost of the weld.

Edge Joints

Edge or flange joints are most commonly used on light-gauge material such as sheet metal. The edges of the sheet metal are turned up in a device called a *brake*. The turned-up edges reduce the danger of burn through on thin materials and at the same time help to prevent distortion. On thin materials, no additional filler metal is required. If selected for plate, the edges must be prepared with one of the variations shown in Figure 14 in order to ensure sufficient penetration.

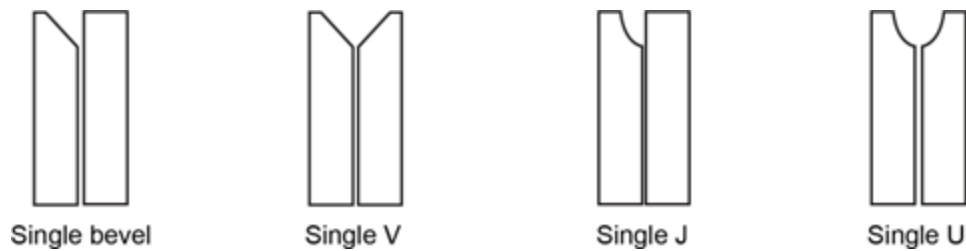


Figure 15 Edge joints (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Butt Joints

Butt joints are the most widely used of the five designs. Like tee joints, butt joints provide maximum accessibility for welding. They use a minimum of weld material and, with 100% penetration, they are effective for all types of stresses. They are the preferred joint for resisting fatigue stresses if complete penetration is assured. The strength of correctly prepared and welded butt joints compares very favourably with the strength of the parent metal.

On thin metal, complete penetration and full strength can be achieved using a square butt joint without extensive edge preparation. On thicker metal, edge preparation becomes increasingly extensive. Two basic designs are used (Figure 16), the bevel and the J. These edge preparations result in eight butt joint variations.

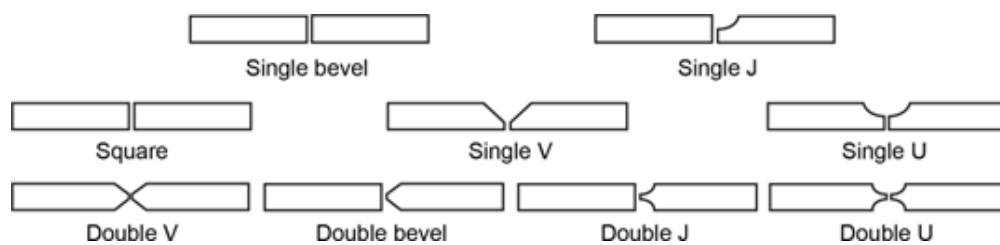


Figure 16 Edge preparation on butt joints (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

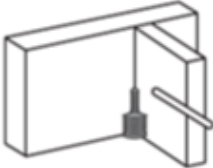
When joints are prepared and welded from both sides, they are called **double joints**. When welded from only one side, they are called **single joints**. To ensure complete penetration, a backing strip or plate is often required.

The drawbacks of the butt joint are primarily in the skill and accuracy required of the welder in fitting and welding the joint. Of the five joints, the butt joint is the most difficult to master. These joints require considerable experience to become proficient in preparing and welding because they often require extra time for back gouging or extra material for backing.

Welding Positions

There are four basic welding positions: flat, horizontal, vertical and overhead. Welding techniques for the four positions vary according to the ease of depositing the metal. Welding in the flat position is generally faster and less tiring than the other three positions and, whenever possible, you should try to place your workpiece in the flat position.

The term “**position welding**” refers to welding in the flat position. The term “*welding out of position*” refers to welding in any of the other three positions. Table 1 and Figure 17 show the four positions that are used.

Table 1: Welding Positions		
Position of Weld	Groove	Tee-joint Fillet
Flat		
Horizontal		
Vertical		
Overhead		

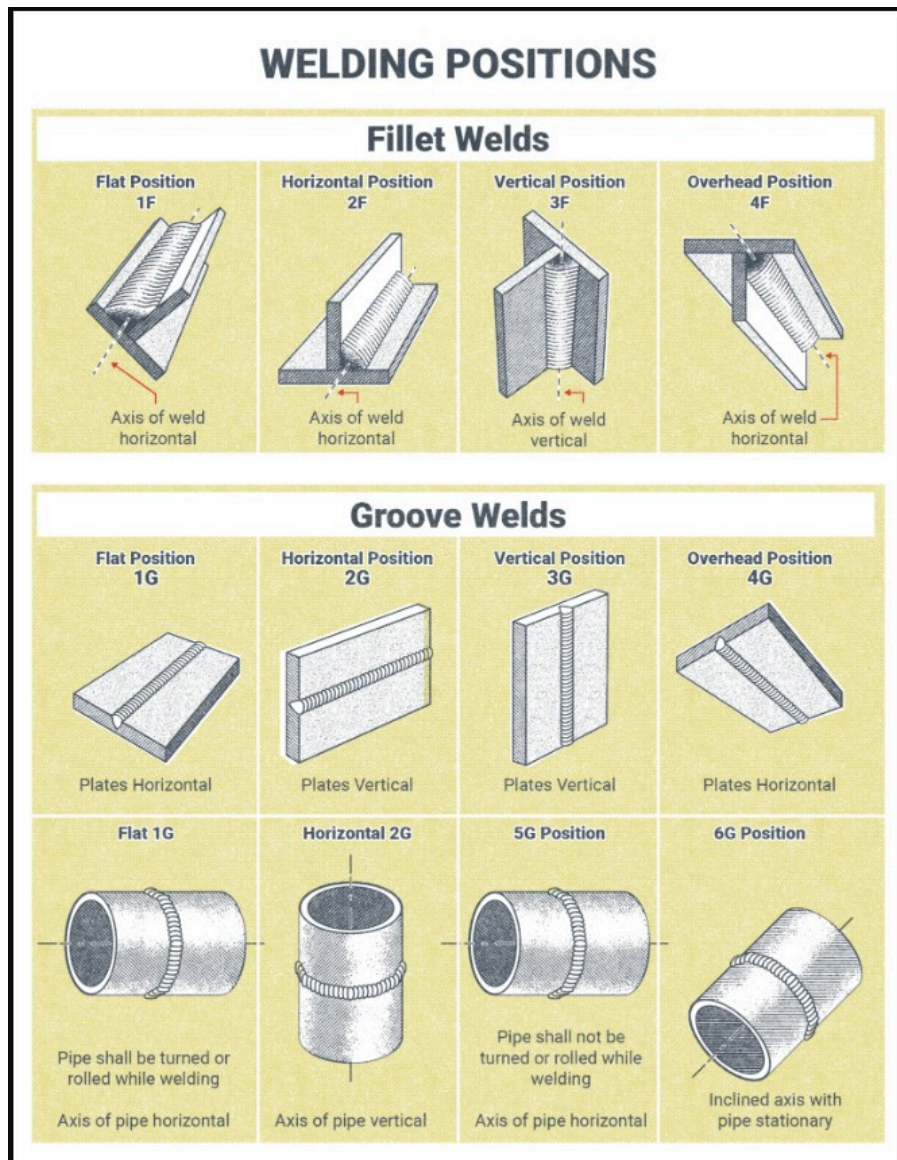


Figure 17 A welding position is determined by the orientation of the weld axis and weld face. Welding position is a critical factor that influences required welding technique, electrical settings, and electrode selection. (Nicholas Malara/OpenWashington) CC BY 4.0 (<http://creativecommons.org/licenses/by/4.0>)

Flat Position

In the flat position, the workpiece is positioned so that the joint is parallel to the floor and the electrode generally points downward. For butt joints on plate, the two pieces are simply placed on a flat surface. For lap and tee joints the two pieces of plate must be supported in an angled position so that the actual joint is parallel to the floor (Figure 18). With corner joints, the ends of the plate are positioned on a flat surface so that the two pieces meet at the top to form a small tent.



Figure 18 Joints in the flat position (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Horizontal Position

Welds in the horizontal position are also parallel to the floor, but they are done along a vertical surface. Weld metal is deposited from the upper side of the joint. For butt joints, the electrode is held horizontally (parallel to the floor), but for the other four joints, it is usually either slightly higher or lower than horizontal, depending on the technique used. For butt joints, the two plates are supported in the vertical position, but the lap, tee and edge joints can be set up and welded on a flat surface. With horizontal welds, the main difficulty is that gravity causes the molten puddle to drip from the lower side of the weld.

Vertical Position

In the vertical position, the plate to be welded is positioned vertically and the weld itself is vertical. The direction of travel may be up or down, but the majority of vertical welding is usually done from bottom to top. The electrode points slightly upward. As with horizontal welding, gravity causes the molten metal to pull away from the edges of the bead and, unless the weld puddle is correctly controlled, molten metal will drip.

Overhead Position

The overhead position is the reverse of the flat position in that the weld is done from the underside of the plate with the electrode pointing upward rather than downward. Overhead welding is considered the most difficult to master. In the overhead position, the force of gravity pulls the molten metal from the toe of the weld bead to the centre of the bead where it can drip or form icicles.

Abbreviations for Weld Position and Weld Type

Abbreviations can be used to indicate the type of weld and the welding position. A fillet weld is often abbreviated to an F, and a groove weld to a G.

Each weld position is designated with a number as follows:

- Flat position (1)
- Horizontal position (2)
- Vertical position (3)
- Overhead position (4)

For example, 1G indicates a groove weld in the flat position; 3F indicates a fillet weld in the vertical position, and 4G would indicate a groove weld in the overhead position.

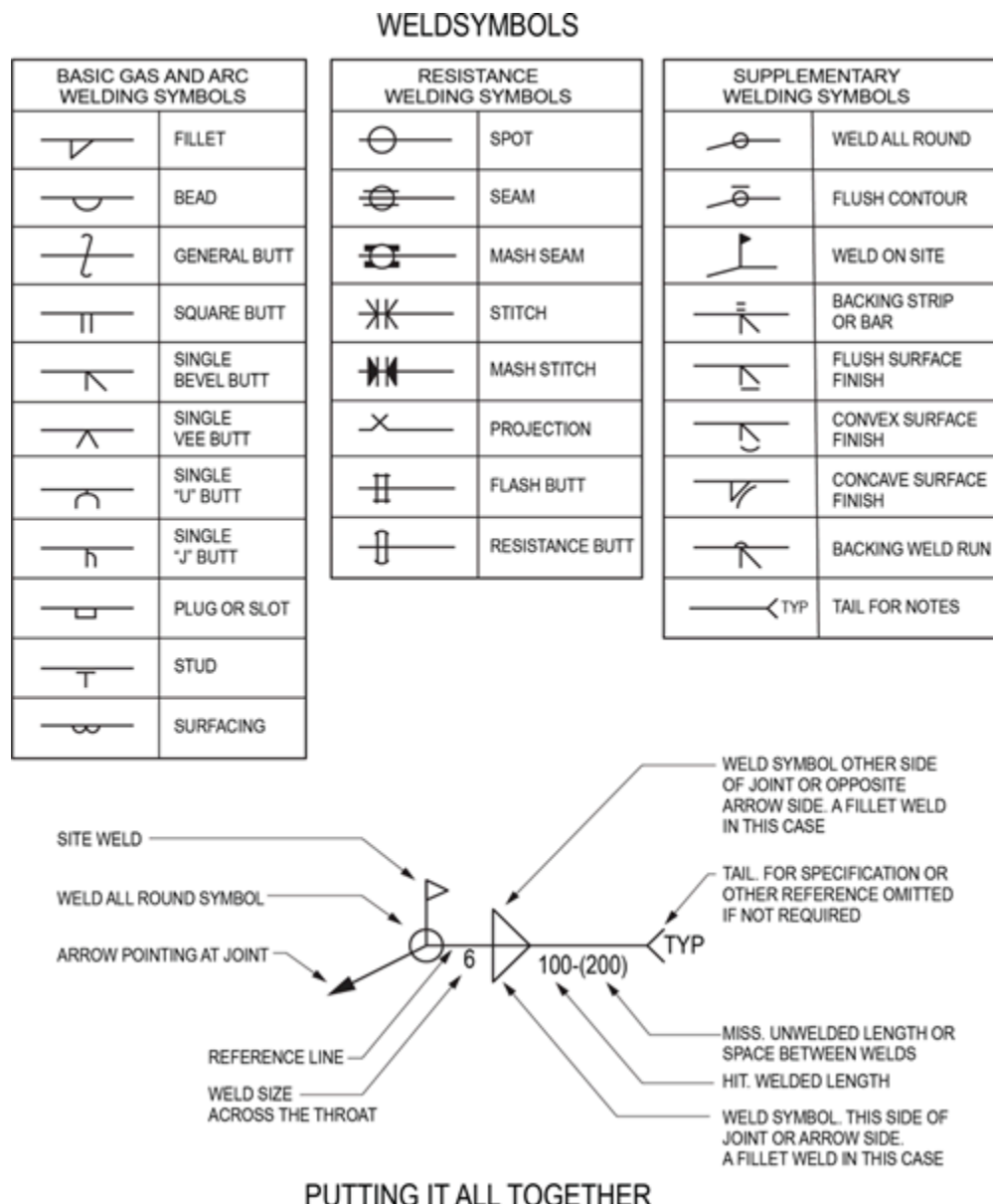


Figure 19 Weld symbols (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Additional Demonstration Videos and Resources

The following videos provide additional demonstrations of common weld types and joint configurations. These resources are intended to reinforce the concepts introduced in this section and to help you visualize proper welding techniques, positioning, and weld profiles in practice.

- Fillet Welds (Tee / Lap / Corner Joints): *Welding SMAW – How to weld a fillet* (<https://www.youtube.com/watch?v=rZGCBty4zM>) [10:49] by IMAT (2019)
- Groove Weld (Butt Joint): *Welding SMAW – How to weld a flat V-groove* (<https://www.youtube.com/watch?v=RGmgFtS5Np0>) [17:13] by IMAT (2019)
- Fillet + Groove Practice (Combined Context): *Tacking up practice welds for fillet and groove welds. Excellent practice exercise.* (<https://www.youtube.com/watch?v=CBb780iu1fA>) [7:15] by Mark Prosser Welds (2019)
- SMAW Fillet Weld (More Technical / Reinforcement): *ARCADEMY: Fillet Welds SMAW* (<https://www.youtube.com/watch?v=fAc1elsA2R0>) [9:52] by American Welding Society (2021)



Self-Test B-6.2: Identify Types of Welds, Positions, Joints and Symbols

Complete Self-Test 6.2 and check your answers.

If you are using a printed copy, please find Self-Test A-6.2 and Answer Key in the Appendix at the end. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.





An interactive H5P element has been excluded from this version of the text. You can view it online here:
<https://b-handmeasuringtools-bcplumbingappr1.pressbooks.tru.ca/?p=3042#h5p-19> (<https://b-handmeasuringtools-bcplumbingappr1.pressbooks.tru.ca/?p=3042#h5p-19>)

References

- BC Industry Training Authority. (2019). *Piping trades apprenticeship program: Use Tools and Equipment—Level 1 harmonized* [Binder]. Crown Publications, Queen's Printer for British Columbia. https://www.crownpub.bc.ca/Product/Details/7960000261_S
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-5: Use welding equipment (Steamfitter)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-5: Use cutting, brazing and soldering equipment (Plumber)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-6: Use oxy-fuel cutting equipment (Plumber)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-6: Use soldering and brazing equipment (Steamfitter)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-7: Use oxy-fuel equipment (Steamfitter)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-7: Use welding equipment (Plumber)*. Crown Publications, Queen's Printer for British Columbia.
- Rupik, D., Colameco, D., Kjeldgaard, C., Ridge, D., Oostman, S., & Fulton, K. (n.d.). *Introduction to welding*. Washington State Board for Community and Technical Colleges. <https://openwa.pressbooks.pub/welding1/>

Media Attributions

All figures are sourced from Industry Training Authority (2019) and/or Camosun College (2019) and are used under the Creative Commons Attribution 4.0 (CC BY 4.0 (<https://creativecommons.org/licenses/by/4.0/>)) licence unless otherwise noted. Images copyrighted by the BC Industry Training Authority are licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 (CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)) licence.

- **Figure 10** Basic Joint Types (<https://openwa.pressbooks.pub/welding1/chapter/wa15-1/>) (Figure 15.1) by Cameron Kjeldgaard, for WA Open ProfTech, © SBCTC (<http://sbctc.edu/>), is used under a CC BY 4.0 (<https://creativecommons.org/licenses/by/4.0/>) licence.
- **Figure 17** Open vs. Closed Root (<https://openwa.pressbooks.pub/welding1/chapter/wa15-1/>) (Figure 15.4) by

Nicholas Malara, for WA Open ProfTech, © SBCTC (<http://sbctc.edu/>), is used under a CC BY 4.0 (<https://creativecommons.org/licenses/by/4.0/>) license.

B-6.3 Describe the Arc Welding Process and Equipment

Principles of SMAW

Shielded metal arc welding (SMAW) is commonly referred to as *stick welding* or *electric arc welding*. An electric arc is the bridge of light and heat that develops when an electric current is forced to leap across a small gap that has been formed in an electric circuit. In the SMAW process, the welding equipment is designed to maintain this arc, and the metals are fused by the intense heat the arc generates.

The flow of electricity in an electric circuit is comparable in many ways to the flow of water in a pipeline. Water flows from a tap because there is pressure in the system. This pressure forces the water to flow through the pipes. The greater the pressure, the more water will flow through a given pipe. The pressure of water in a system is measured in kilopascals (kPa) or in pounds per square inch (psi). The flow of water is measured in cubic metres per hour (m^3/h) or in cubic feet per hour (ft^3/h).

The electricity that flows through the conductors of an electric circuit does so because there is electrical “pressure” created by a generator at the power source. This electrical pressure is called **voltage** and is measured in **volts (V)**. The flow of electricity is called **current** and is measured in **amperes (A)**.

To do useful work, an electrical current must flow through the conductors in a closed electrical circuit. If for some reason this circuit is broken (or opened), the flow of electricity will stop. Electrical pressure (*voltage*) will continue to exist while the generator runs, and current will resume as soon as the circuit is completed (closed) again. An arc welding circuit is basically an electric circuit that the welder can close and open as required.



Figure 1 Shielded metal arc welding Lincoln Excalibur 7018 1/8" (Prowelder87/Wikimedia Commons)
CC BY-SA 4.0 (<https://creativecommons.org/licenses/by-sa/4.0>)

Applications of SMAW

Almost any requirement for welding mild and stainless steel and cast iron can be accomplished using the SMAW process. Its uses include:

- Shipbuilding
- Locomotive and boiler making
- Structural work
- Engineering applications
- Building
- Maintenance and repair of industrial and farm equipment
- Light gauge welding
- The assembly of automobiles
- The welding of pipelines



Figure 2 Gas pipeline welding (Hamid Soufi/Wikimedia Commons) CC BY-SA 3.0
(<https://creativecommons.org/licenses/by-sa/3.0>)

Power Source

The welding machine that provides the source of power for arc welding is an extremely important part of the process. Power sources for SMAW may supply either **alternating current (AC)** or **direct current (DC)**. They also have controls so that the welder can vary the current to meet the requirements of different welding tasks, materials, and positions.

Alternating Current

With AC, the direction of current flow rapidly reverses 120 times per second. A complete direction change from zero to maximum volts at one pole, then back to zero volts and up to maximum voltage at the other pole is called a **cycle** and occurs 60 times per second. Most electrical utility companies distribute alternating current at 60 cycles per second. This means that 60 times a second the voltage reaches a maximum in one direction, and 60 times per second it reaches a maximum voltage in the other direction.

Some of the characteristics of alternating current can be represented in the form of a **sine wave** diagram (Figure 3).

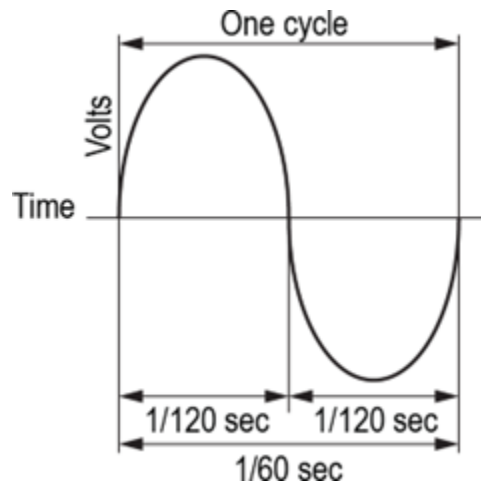


Figure 3 Alternating current sine wave (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

In comparison with the rapid fluctuations of alternating current, DC current flows from one pole continuously without fluctuation (Figure 4).

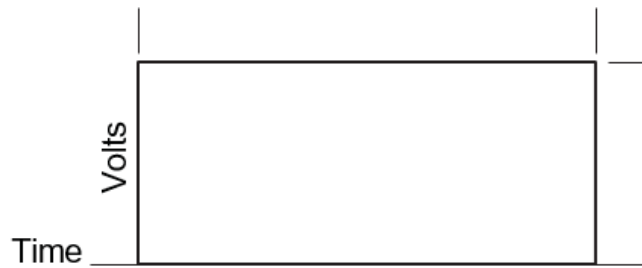


Figure 4 Direct current level (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Alternating current may be **single-phase AC** (Figure 5) or **three-phase AC** (Figure 6).

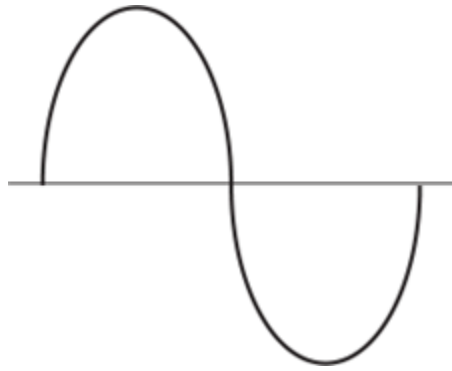


Figure 5 Single-phase AC (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

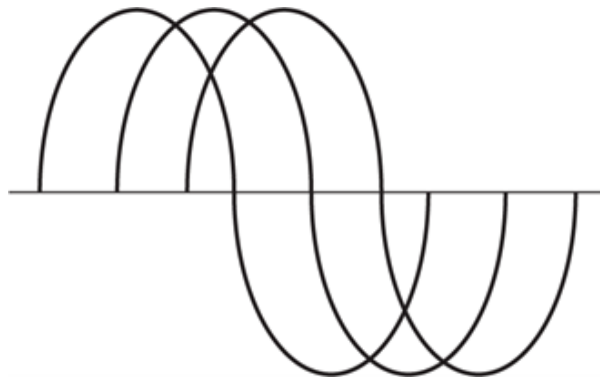


Figure 6 Three-phase AC (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Single-phase AC power is useful for most domestic and light industrial operations. However, as Figure 5 shows, there is a considerable period of time during each cycle when less than maximum power is being delivered. This makes single-phase power inefficient for heavy industrial uses, including some welding applications.

Three-phase AC power is more often used for industrial jobs. Three-phase AC power utilizes three single-phase currents timed to start at regular intervals from each other (Figure 6). The advantage of three-phase power is that even though one phase may be delivering only minimum power, one of the other two phases will be delivering nearly maximum power. Welding machines that use three-phase power are generally more compact and produce a smoother arc than single-phase machines.

Direct Current

With **direct current**, the electrons in a circuit flow in one direction only from the negative to the positive pole. This type of current is produced by DC generators and by batteries.

Polarity

Electron flow in an electrical circuit is always from the negative pole to the positive. However, the practical effects of this for welding are more important with DC welding current (Figure 7). With direct current, the electron flow is in one direction only and, depending on how you connect the circuit, the current flow can be made to affect the heat of the **electrode** or of the workpiece.

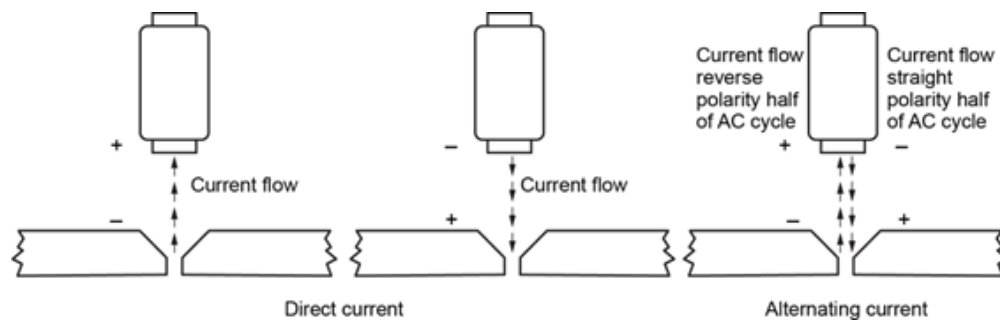


Figure 7 Effects of polarity (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

The **polarity** of a DC welding circuit can be used in two ways:

- **DCEN** (DC electrode negative) connects the welding circuit so that the electrode is attached to the negative pole of the power source to concentrate heat in the workpiece (Figure 8)
- **DCEP** (DC electrode positive) connects the welding circuit so the electrode is attached to the positive pole of the power source to concentrate heat in the electrode

When using coated electrodes in SMAW, DCEN (negative) generally allows for faster welding speeds and for higher filler rod deposit. It provides a medium depth of penetration. With DCEP (positive), the heat can be concentrated at the electrode. With this polarity, you can achieve a deeper penetration in the weld, but the welding speed is slower.

Controls

On most DC motor and engine-driven generators for SMAW, there are controls for both current and voltage levels. That way, the welder can alter the shape of the volt-amp curve and adjust the characteristics of the arc to suit the requirements of a particular welding task. These machines are called **dual-control machines**.

The controls may be of the tapped type (offering a range of specific settings) or the continuous control type that allow for infinite setting adjustment. On the tapped or stepped type of control, the dial must be set precisely on a given setting. Current values between settings cannot be obtained, and the device may suffer damage if you attempt to place the dial between settings. Instead, the fine adjustments that you require to accommodate the metal thickness, electrode size and type, and welding position for a given job are secured by using the fine adjustment control.

On machines with dual continuous controls, the **coarse adjustment dial** (sometimes known as the *job selector dial*) allows for continuous variation of current level. The second of the two controls allows for fine adjustment of the current and voltage. By manipulation of the two dials together, the slope of the volt-amp curve can be adjusted for any particular current level within the output range of the machine.

Fuel-Engine-Driven AC and AC/DC Welding Machines

A fuel engine can also be made to drive an alternator to produce AC current. As with the transformer/rectifier described earlier, some alternator machines feed the current into a rectifier to make DC current available in the same machine. The control devices on these welding machines are essentially the same as those described for the DC generators.

The Arc Welding Circuit

The SMAW welding circuit consists of:

- A power source
- A ground cable and clamp
- An electrode cable
- A welding electrode and electrode holder
- The workpiece

When the electrode is touched to the workpiece and then withdrawn a short distance, the arc is struck and the electrical circuit is completed. The current flows through the electrode, across the arc, through the workpiece, and through the ground clamp and cable, then returns to the power source.

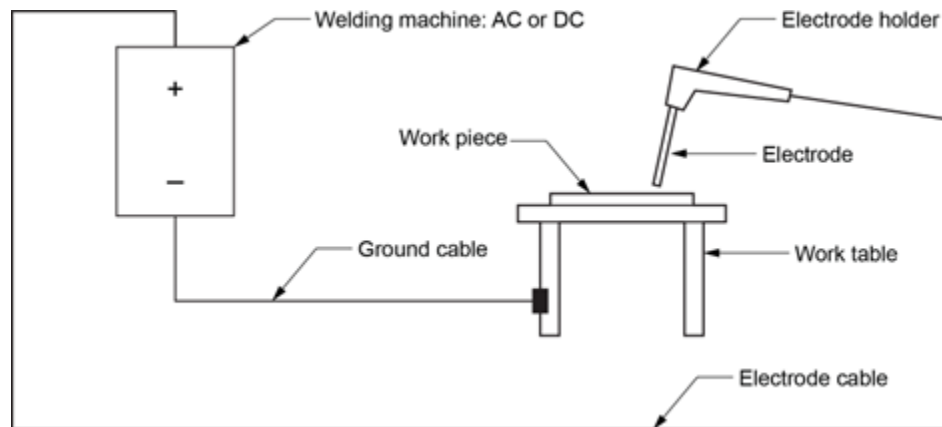


Figure 8 Arc welding circuit (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

The SMAW Process

When the power source for a welding circuit is turned on, but before the arc has been struck, the circuit is open. At this point, the voltage or the potential in the circuit is at its maximum and is called the “**open-circuit voltage**.” The moment the welder strikes the arc, the circuit is closed (completed), the voltage drops to what is called the “**arc voltage**,” and the high current in the welding circuit flows.

As the current crosses the arc from the electrode to the workpiece, tremendous heat is generated (anywhere from 5532 °C to 6632 °C). The heat melts the end of the electrode and the parent metal in the workpiece directly beneath the arc, forming a pool of molten metal. As the electrode melts, small particles of molten metal are carried across the arc stream and deposited in the molten pool on the parent metal, forming the **weld deposit**. This weld deposit is actually a mixture of the melted electrode and the melted parent metal. At the same time, the force of the arc digs into the workpiece and provides the necessary depth of penetration for the weld.

Electrodes

The electrodes used in the SMAW process are not bare but are covered with a **flux**. They have a core that consists of either a solid metal wire or a metal tube containing metal powders. The metal core conducts the electric current to the arc and provides the **filler metal** for the weld joint. This filler metal is deposited as the electrode is gradually consumed and as the welder moves the arc over the workpiece at the correct arc length and travel speed.

The coating of the electrode helps keep the arc stable and concentrated on a precise point on the weld. As the chemicals in the electrode coating are vapourized, they provide the shielding required to protect the molten metal from contamination by the atmosphere, hence the name “*shielded metal arc welding*.”

Welding electrodes are both fragile and expensive, so they require careful treatment. This treatment must be exercised both before and during the use of an electrode.

Handling of Electrodes Before and After Use

Handle electrodes with great care to avoid breaking or cracking the coating. An electrode that has received damage to the coating will usually perform poorly and, if pieces of the coating are actually missing, the result may be slag inclusion in the weld.

Because electrodes with very different properties may look the same, correct handling of electrodes also includes marking them accurately after the package has been opened. It is equally important to collect and clearly mark unused electrodes that are being returned to storage. Do not risk producing a weld that does not meet specifications because you used the wrong electrode. An electrode that is not clearly identified should be considered unusable.

Storage of Electrodes

A perfectly dry electrode is essential for a satisfactory weld. **The main requirement for storage of electrodes is keeping them dry.** In addition to being fragile, the composition of electrode coatings allows them to pick up moisture from the air. Prolonged exposure to moisture can result in disintegration of the coating. Even if the disintegration is not obvious, the heat of the arc will blow away portions of the coating. In either case, the electrode is rendered useless and must be discarded. Low-hydrogen electrodes must be thrown away if they have been directly exposed to water.

Moisture that is absorbed by an electrode contains hydrogen and, during welding, some of this hydrogen is transferred to the weld metal. This can lead to a number of problems with the weld. Depending on the composition of the base metal, these problems can include **embrittlement**, **porosity**, cracking of the weld, and a rough weld appearance. In

addition, welding with a moist electrode increases the arc voltage, increases weld spatter, and makes slag removal difficult.

Some electrodes (such as mineral-coated ones) are more prone to absorbing moisture than others.

The length of time electrodes can be exposed to the atmosphere varies from 30 minutes to 4 hours or longer, depending on the relative humidity of the atmosphere. For example, with low-hydrogen electrodes, the maximum exposure time is between two and four hours, depending on the relative humidity. With all electrodes, it is impossible to tell simply by visual examination whether they have absorbed dangerous amounts of moisture.

To protect electrodes from moisture, manufacturers ship them in air-tight containers. Sealed portable containers are used on the job for storing the supply of electrodes.

Electrode Ovens

Some electrodes can be safely stored in normal room conditions, provided that temperature and relative humidity do not exceed certain normal tolerances. **Electrode ovens** are widely used to guarantee a humidity-controlled environment for storing electrodes. Ovens are essential for the more sensitive low-hydrogen and hardsurfacing types and for special alloy electrodes such as stainless steel, brass, bronze, aluminum, **inconel** and **monel**. Electrode ovens may be the large type found in welding shops capable of holding several hundred pounds of electrodes or the smaller field ovens that can be connected to an auxiliary power supply.

Ovens are also useful for restoring electrodes that may have been exposed to a certain level of moisture, but that can be rebaked to make them usable. Electrode manufacturers and suppliers provide information on storage and rebaking conditions for their electrodes and, if available, these recommendations should be followed.

Electrode Holder

The **electrode holder** (Figure 9) or “stinger” is the device used to carry the welding current to the welding electrode. It is also the means by which the welder holds the electrode while welding. The two most common types of electrode holder are the jaw type and the twist-head type. The jaw type grips the electrode between two jaws activated by a powerful spring. The twist-head type secures the electrode in place through the screw action of the head. The handle of any type of electrode holder is extremely well insulated to protect the welder against electric shock and heat.



Figure 9 Electrode holders (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Because it is the part of the welding circuit that the welder actually contacts, the electrode holder must be kept clean and in good condition to minimize any risk of shock. Replace any damaged insulation and clean the grooves of the jaw to remove any weld spatter that has collected.

The connection between the welding cable and the holder is a vulnerable point in the welding circuit because it is constantly being flexed during welding operations. This connection is usually mechanical and must be inspected every time you weld.

Ensure that the connection is tight. Loose connections increase electrical resistance and cause additional heat that can wear down insulation. Check the connection for broken strands of cable, as these too can cause heat buildup and can deteriorate the insulation. Should the connection have broken strands, cut off the damaged end and make a new connection, either mechanically or by soldering or brazing, before you start any welding.

Ground Clamps

At the other end of the welding circuit is the **ground clamp** or *ground connection*, which is necessary to make the welding circuit complete.

Without a good ground connection, there can be a loss of power through increased resistance, a risk of fire from sparking, and increased danger of electric shock.

The ground connection may be attached to a welding table or bench that is equipped with a permanently bolted or tack-welded lug or with an insulated terminal. If welding is not being done on a welding bench, the ground may be connected to the workpiece by means of a clamp. Clamps are of different types, the most common being the spring-loaded, C-clamp, rotary clamp, and magnetic clamp.

Electrode Stubs

Electrodes should be used down to a stub length of 50 mm (2") or less. These **electrode stubs** should be disposed of in fireproof metal containers. If you throw them on the floor, they create a slipping hazard.

Slag

The coating that forms on the top of an arc weld is called **slag**. When it is first deposited it is very hot. It has to be removed after it has cooled and has become solid and hard. As you chip off slag, ensure that fragments do not hit you or anyone else.



Do not look directly into a laser beam! Looking directly into the beam may be hazardous to your eyes. A quick flash of the beam is not a problem, but prolonged exposure should be avoided. The instrument must be positioned either above or below the worker's line of sight.

Portable Grinders

Grinders are used to prepare metal for welding, clean fresh welds, and remove weld faults to be re-welded.

When the workpiece is too large to bring to a bench or pedestal grinder, you can grind it by using a portable grinder. Portable grinders may be powered by compressed air or by electricity and are classed as either straight grinders or angle grinders.

Straight Grinders

Straight grinders are so named because the drive shaft, which turns the grinding wheel, is aligned with the motor (Figure 10).

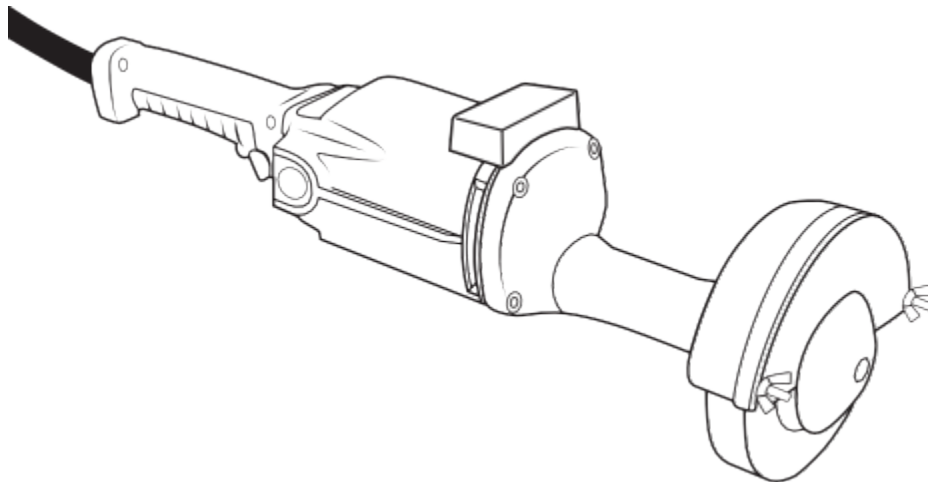


Figure 10 Straight grinder (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Straight grinders are available in a variety of sizes and shapes. Larger ones are used for the quick removal of metal, while small models are used in hard-to-reach areas.

The larger models of straight grinders have a grinding wheel approximately 150 mm (6") in diameter. You must hold these larger models with both hands.

Small **pencil grinders (die grinders)**, as illustrated in Figure 11, are used to remove small metal burrs from freshly drilled holes, for elongating holes and slots and for preparing material for welding in tight places. These grinders turn at very high speeds (25 000 revolutions per minute [RPM] or more).

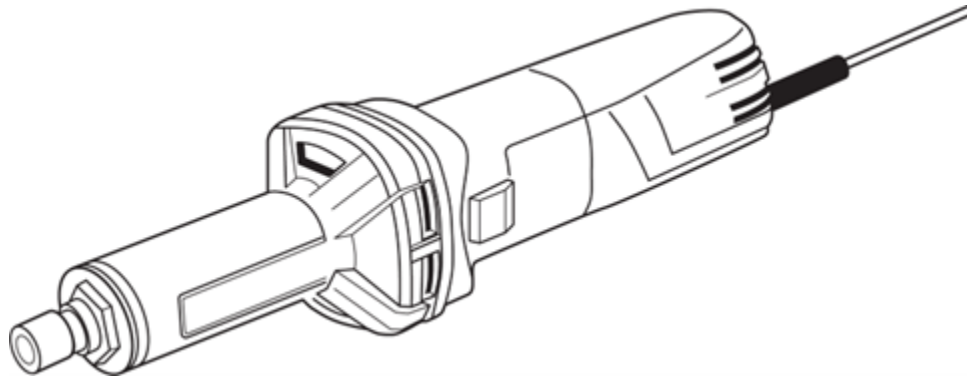


Figure 11 Small straight grinder (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

These small grinders use a small grinding stone or a carbide cutting burr mounted on their shafts (Figure 12).

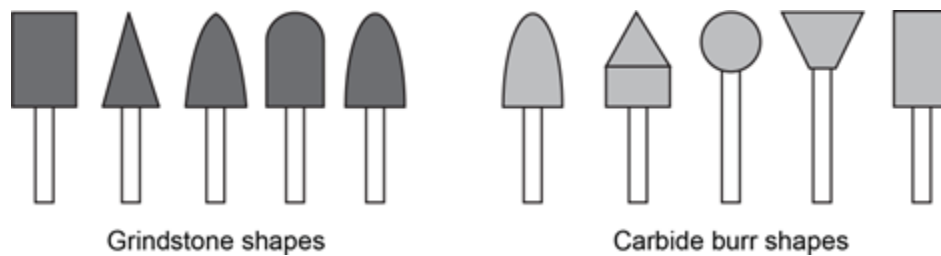


Figure 12 Grindstone and carbide burs (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Angle Grinders

Angle grinders have a grinding disk which rotates at 90° to the axis of the motor. This versatile tool comes in various sizes (Figures 13 and 14). Disks range in diameter from 75 mm (3") to 225 mm (9"), and each disk type and size has its RPM rating identified. When you select a disk, make sure its RPM rating either matches or exceeds the RPM of the grinder.



Figure 13 Angle grinder on concrete (Asumnupal/Wikimedia Commons) CC BY-SA 4.0 (<https://creativecommons.org/licenses/by-sa/4.0/>)

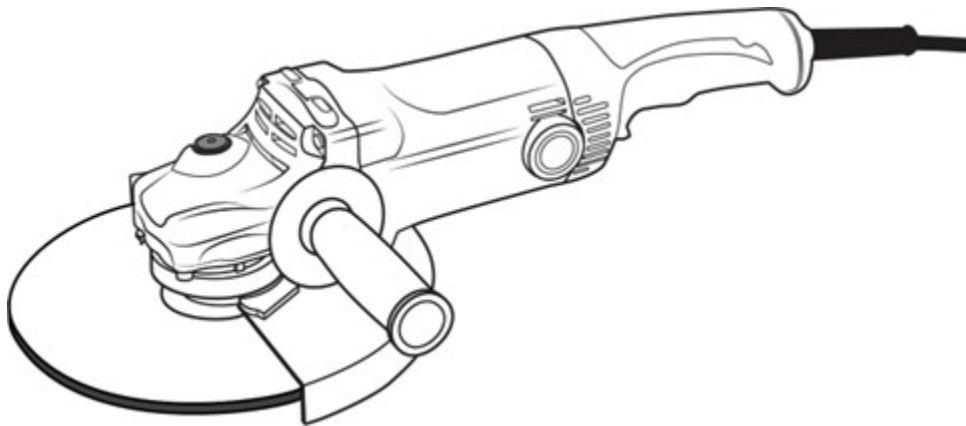


Figure 14 Angle grinder (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

An angle grinder has a guard covering half the disk and it is held to the workpiece so that only the exposed portion of the disk makes contact with the workpiece.

Disks other than for grinding are available for angle grinders (Figure 15). With these disks, the angle grinder becomes much more than a grinding tool. It is a very versatile and useful tool.

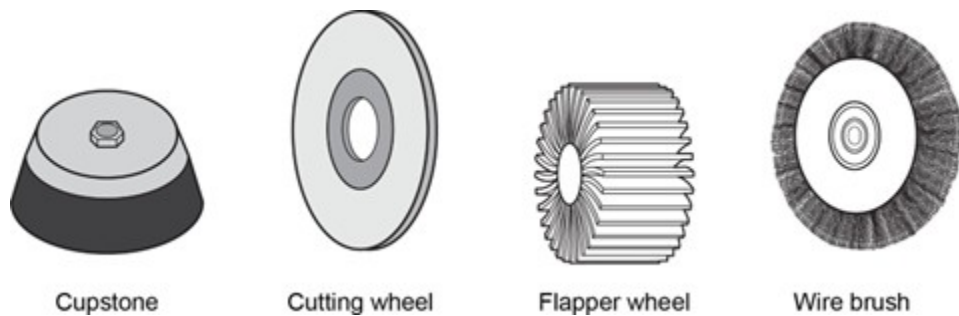


Figure 15 Other disks for angle grinders (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Cables

Current is conducted from the welding machine to the electrode and electrode holder by the electrode cable and from the workpiece to the welding machine by the ground or work cable. These cables are made from insulated copper or aluminum wire. Aluminum wire has the advantage of weighing less than copper and can dissipate heat more quickly, but it can carry only about 60% of the current load of copper wire.

The electrode cable is specially designed to enable the welder to move the electrode and holder without putting undue strain on the cable.

A typical electrode cable (Figure 16) consists of thousands of hair-like wires braided into strands. These strands are themselves braided to form the conductor and are enclosed in a durable paper wrapping that allows the conductor to move easily inside the insulation when it is bent. Outside the paper is a layer of rubber insulation surrounded by a layer of woven fabric reinforcement to provide additional wear resistance. The outer layer is special composition rubber with a smooth finish, highly resistant to wear.

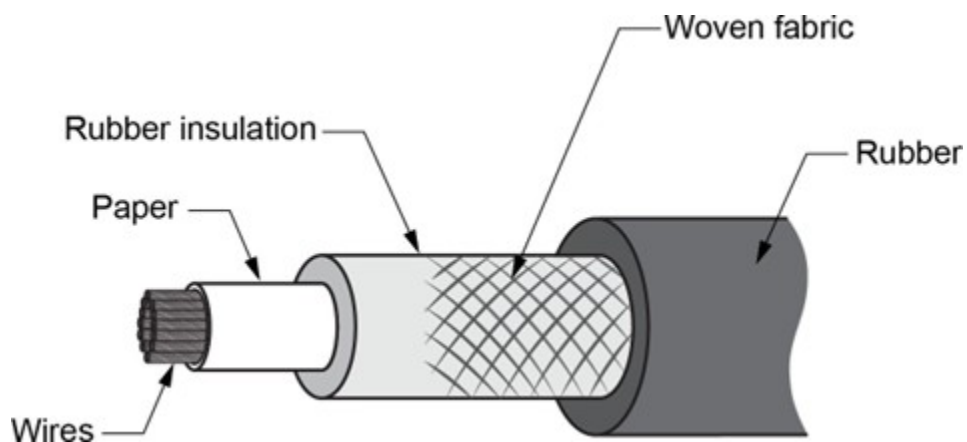


Figure 16 Typical electrode cable (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

The ground cable does not usually undergo as much movement as the electrode cable, so less flexible but equally wear-resistant cable is used.

Summary

As you prepare to weld, remember these main safety points:

1. Always turn off your welding machine when it is not in use.
2. Wear gloves when handling arc welding equipment.
3. Keep all equipment dry and do not work in damp or wet conditions.
4. Make sure that the workpiece or workbench is properly grounded.
5. Do not overload the welding cables.
6. Remove the electrode from the electrode holder before putting the holder down.
7. Switch the welding machine off when your work is completed.

General Maintenance of Welding Machines

A welding machine must be maintained even when it is not in use. Make sure that equipment is stored where it will not be damaged when you are using other equipment. Protect portable welding machines from severe weather conditions.

Operate the machine as it was designed to be operated. When you use a machine, locate it so that it is well ventilated by cool, clean air. Keep it as far as possible from the dust of grinders and cutting machines. Keep it away from heaters and other heat-producing equipment and away from welding spatter. This will reduce the daily wear and tear.

Never use the current range or the polarity switch of a machine when there is a load on the circuit. Use these switches only when the machine is off or is idling before the arc is struck. Otherwise, the load may cause an arc in the switch and permanently damage the contacts.

Routine maintenance procedures that you can perform on welding machines include inspecting all cable connections to ensure that loose connections are not increasing wear on the equipment by adding to the circuit resistance. On portable fuel engine machines, check coolant levels and oil levels before each use.

Most AC-transformer-type welding machines have a forced air circulation cooling system powered by an electric motor connected to the primary circuit. As well as keeping the vent openings clear any time the machine is in operation so that the flow of air is unobstructed, remove the casing and thoroughly clean the passageways at least twice a year. In those units (such as motor-generator machines) that have air filters, inspect the filters regularly and clean them as required.

Storage

Store welding equipment in a dry location. Neatly roll cables in fairly large loops to reduce stress on the fibres and store them with like lengths so that they are easy to select for the job at hand.



Self-Test B-6.3: Describe the Arc Welding Process and Equipment

Complete Self-Test 6.3 and check your answers.

If you are using a printed copy, please find Self-Test A-6.3 and Answer Key in the Appendix at the end. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.



An interactive H5P element has been excluded from this version of the text. You can view it online here:
<https://b-handmeasuringtools-bcplumbingapprl1.pressbooks.tru.ca/?p=3046#h5p-20> (<https://b-handmeasuringtools-bcplumbingapprl1.pressbooks.tru.ca/?p=3046#h5p-20>)

References

- BC Industry Training Authority. (2019). *Piping trades apprenticeship program: Use Tools and Equipment—Level 1 harmonized* [Binder]. Crown Publications, Queen's Printer for British Columbia. https://www.crownpub.bc.ca/Product/Details/7960000261_S
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-5: Use welding equipment (Steamfitter)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-5: Use cutting, brazing and soldering equipment (Plumber)*. Crown Publications, Queen's Printer for British Columbia.

Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-6: Use oxy-fuel cutting equipment (Plumber)*. Crown Publications, Queen's Printer for British Columbia.

Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-6: Use soldering and brazing equipment (Steamfitter)*. Crown Publications, Queen's Printer for British Columbia.

Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-7: Use oxy-fuel equipment (Steamfitter)*. Crown Publications, Queen's Printer for British Columbia.

Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-7: Use welding equipment (Plumber)*. Crown Publications, Queen's Printer for British Columbia.

Media Attributions

All figures are sourced from Industry Training Authority (2019) and/or Camosun College (2019) and are used under the Creative Commons Attribution 4.0 (CC BY 4.0 (<https://creativecommons.org/licenses/by/4.0/>)) licence unless otherwise noted. Images copyrighted by the BC Industry Training Authority are licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 (CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)) licence.

- **Figure 1** Shielded metal arc welding (https://commons.wikimedia.org/wiki/File:Shielded_Metal_Arc_Welding_.jpg) Lincoln Excalibur 7018 1/8" by Prowelder87 on Wikimedia Commons is used under a CC BY-SA 4.0 (<https://creativecommons.org/licenses/by-sa/4.0/>) license.
- **Figure 2** Gas pipeline welding, Azna 2017 (https://commons.wikimedia.org/wiki/File:Gas_pipeline_welding_,_Azna_2017.jpg) by Hamid Soufi on Wikimedia Commons is used under a CC BY-SA 3.0 (<https://creativecommons.org/licenses/by-sa/3.0/>) license.
- **Figure 13** Faschina-concrete angle grinder-Betontrennschleifen-13ASD (https://commons.wikimedia.org/wiki/File:Faschina-concrete_angle_grinder-Betontrennschleifen-13ASD.jpg) [Angle grinder on concrete], by Asumnial on Wikimedia Commons is used under a CC BY-SA 4.0 (<https://creativecommons.org/licenses/by-sa/4.0/>) license.

B-6.4 Use Arc Welding Equipment

Achieving welds of high quality involves skill and concentration, which you will only develop through considerable practice. Consider the following five factors before each weld:

- Operator comfort and position
- Machine setting
- Arc length
- Electrode angle
- Speed of travel

Operator Comfort and Position

It is easier to weld if you are in a comfortable position and if you have a clear view of the area in front and behind the electrode. Most welders find that by placing their arms correctly, they can maintain control of the arc yet remain comfortable

If you are right-handed, grasp your right wrist with your left hand and place your left elbow on the welding bench. Use your left elbow as a pivot while you move the electrode along the metal. The usual direction for flat position welding for right-handed welders is from left to right. If you are left-handed, your arm positions and weld direction will be reversed.

Machine Setting

Before each weld using DC current, you must check that the polarity setting (either straight or reverse) is correct for the type of electrode you are using. With AC current, you have no choice of polarity, since the circuit is alternately positive, first on one side and then on the other.

You must also make sure that the current or amperage is correctly set for the electrode you are using, the type of joint, the weld position, the type of material to be welded, and the speed required for the weld. The current setting determines the welding temperature that will affect the quality and soundness of the weld.

Arc Length

The **arc length** (the distance of the electrode from the workpiece) is usually determined by the diameter of the electrode, with consideration to the welding position and the required amount of current. When the arc length is correct, the arc makes a distinct crackling sound. When it is too long, the crackling changes to a hissing sound.

Welding arcs that are too long prevent good penetration and fusion, permit the absorption of oxygen and nitrogen into the weld, and produce excessive weld spatter. In addition, they increase the possibility of arc blow.

Electrode Angle

Generally, the electrode should be held perpendicular to the base metal and then inclined 20° to 30° in the direction of travel (Figure 1). For some welds, however, the **electrode angle** is required to remain upright, perpendicular (90°) to the workpiece.

The correct angle is important in preventing *undercut* and slag inclusions. It also makes it easier for you to deposit weld metal and to achieve complete penetration and fusion.

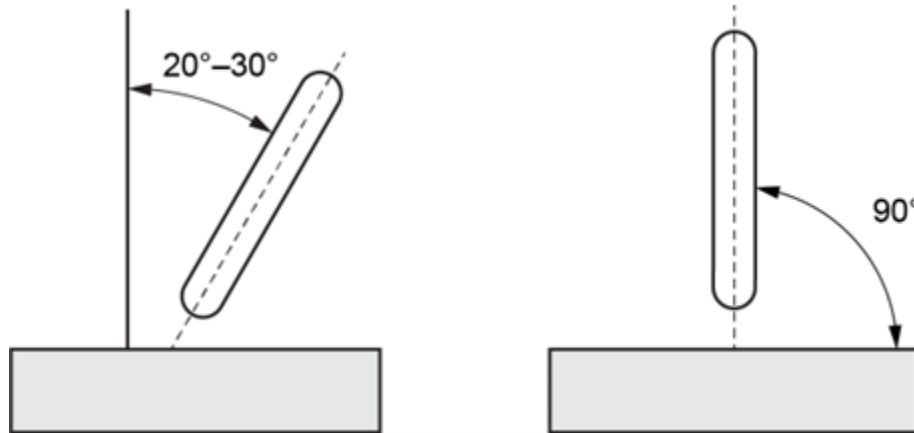


Figure 1 Electrode angle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Speed of Travel

Generally, the **speed of travel** should be such that 25 mm (1") of electrode produces 25 mm (1") of deposit. This speed is only an average and may need to be increased or decreased, depending on the welding position and the heaviness of the deposit required.

Weld Faults

There are three categories of weld defects:

- **Dimensional faults** vary from the specifications and requirements of the weld, including incorrect weld sizes and profiles
- Structural discontinuities, including such defects as porosity, undercut, incomplete penetration, and lack of fusion
- Defects in the mechanical properties of the metal, including reduced tensile strength, ductility, hardness or corrosion resistance

Defects in mechanical properties are not a factor that you can control.

Dimensional Defects

Incorrect Weld Size

Any variation from the specified weld size influences the distribution of stress in the weld. This will affect the strength of the weld. Welds that are undersized usually have insufficient throat (Figure 2), which substantially reduces the strength of the weld. Stresses concentrate at the centre of the weld, increasing the likelihood of joint failure. Undersized welds are usually the result of a fast rate of travel.

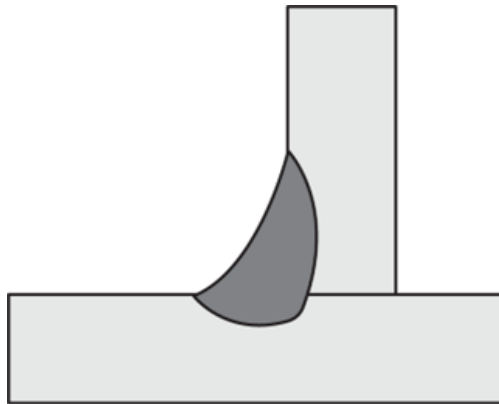


Figure 2 Undersized weld (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Oversized welds display excessive convexity on fillet welds and excessive reinforcement on groove welds (Figure 3). These defects tend to produce notches at the toe of the weld where stresses will concentrate. The metal also tends to entrap slag and gases, creating a condition called porosity, which undermines the strength of the weld. Inadequate fusion of the weld and parent metal is also associated with excessive convexity or reinforcement.

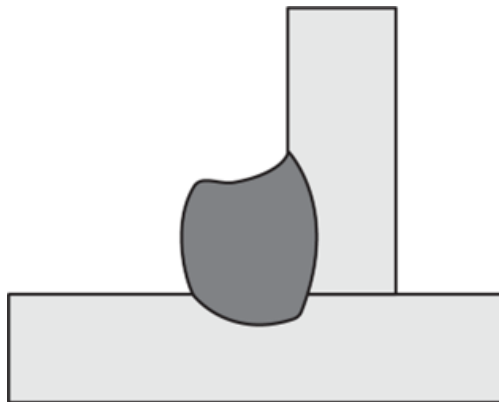


Figure 3 Oversized weld (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Overlap

Overlap is a condition in which excess weld metal is deposited at the toe of the weld. It is most often a sign of poor fusion between the weld and parent metal (Figure 4). This condition is extremely serious, as stresses concentrate in notches that form at the toes of the weld. In fillet welds, overlap may also reduce the size of the weld.

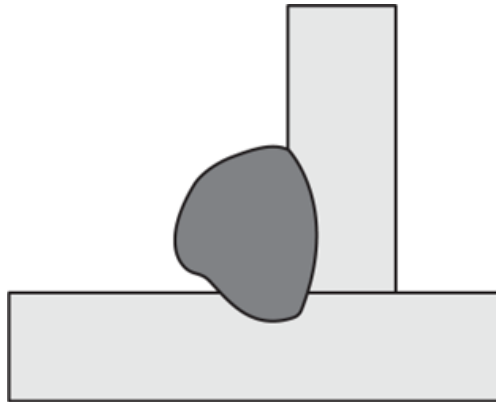


Figure 4 Overlap (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Dimensional defects also include the distortion and warping that occur as a result of stresses from heating and cooling the metal during welding.

Structural Discontinuities in the Weld

Structural discontinuity incorporates a broad range of weld defects that include:

- Undercut
- Porosity
- Incomplete penetration
- Slag and gaseous inclusions
- Lack of fusion
- Cracking

While these defects often accompany other defects associated with size and profile problems, they may also occur in welds that conform to size and profile specifications.

Undercut

Undercut refers to a cutting away of the plate surfaces at the edge of the weld (Figure 5). A sharp recess forms in the

plate where the next layer or bead must fuse with the parent metal. At this point, plate thickness is reduced, weakening the joint. The possibility of joint failure is particularly high when the undercut occurs at the toe of the weld.

Undercut is generally caused by improper electrode manipulation, but too much current, too long an arc, or slow travel can also be contributing factors. On joints that are not very accessible, undercut may be very difficult to avoid.

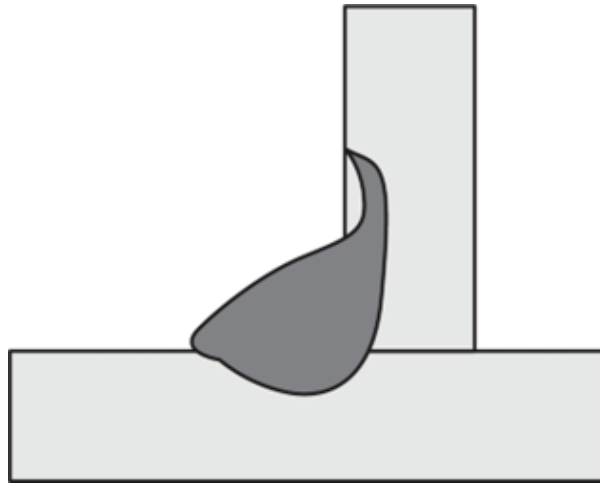


Figure 5 Undercut (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Undercut can be corrected. When it occurs at the sidewall of the weld between passes, extra metal can be deposited in the recess before the next bead is deposited. At the surface of the weld where the defect of the weld is visible, additional metal can be used to fill up the recess.

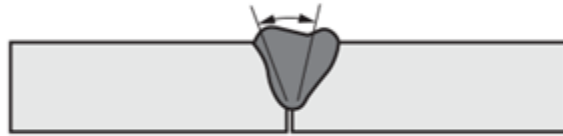
Incomplete Penetration

Incomplete penetration is the failure of the weld metal and the base metal to fuse together at the root of the joint. On groove and fillet welds, this defect occurs when the areas above the root reach temperatures before the root. The molten metal forms a bridge across the joint and prevents the arc from reaching the root.

Incomplete penetration is most often caused by a joint design that is not suitable for the welding process selected. For single groove welds, this defect is most likely the result of one of the conditions shown in Figure 6 .



Root opening too small



Included angle too small



Root landing too large

Figure 6 Incomplete penetration (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Even when the joint is correctly designed, incomplete penetration may be caused by welding procedures. With a current that is too low, the weld metal is not able to reach the root of the joint or the arc is not strong enough to melt the base metal at the root. If the rate of travel is too fast, the metal is deposited on only the surfaces above the root. Electrode size is also an important factor, especially on the root bead. If the electrode is too large, it will not penetrate the narrow root opening.

Lack of Fusion

Lack of fusion is the failure of the welding process to fuse adjacent layers of weld metal or adjacent weld metal and base metal (Figure 7). This failure may occur at any point in groove and fillet welds. Overlap at the toe of the weld is often a sign of inadequate fusion.

Lack of fusion usually results from the following conditions:

- failure to heat the base metal or the previously deposited weld metal to the melting point, which usually occurs if the electrode is too small, the travel is too fast, or the current is too low
- failure to dissolve, by correct fluxing, the oxides or other foreign material on the surfaces to be welded



Figure 7 Lack of fusion (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Porosity

Porosity refers to the presence of voids in the weld that do not contain any weld metal (Figure 8). Porosity may be distributed uniformly throughout the weld or may be clustered. Although excessive porosity has a serious effect on the mechanical properties of the joint, some welding codes allow for a specified maximum amount of porosity.

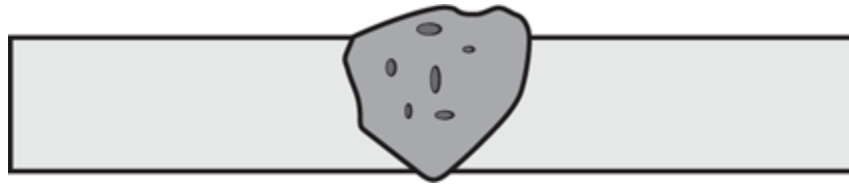


Figure 8 Porosity (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

When pockets are concentrated at the root, they are often referred to as wormholes or piping. This condition is regarded as a special case of *incomplete penetration*.

Porosity results from the inclusion of gases in the weld. These gases are formed by the chemical reactions that take place in the weld as the metal is heated and cooled. Porosity generally occurs as a result of one of the following factors:

- Overheating or under-heating the weld metal
- Excessive sulphur or moisture in the base metal or electrode
- Current too high or too low
- Incorrect electrode manipulation
- Oil or other contaminants on the joint
- Defective or unsuitable electrodes
- Too long an arc
- Arc blow

Slag Inclusion

Slag refers to the metallic oxides and other solid compounds that are produced by chemical reactions during the welding process. Sometimes slag can become trapped in the weld. Like gaseous inclusions, they create porosity in the weld metal (Figure 9).

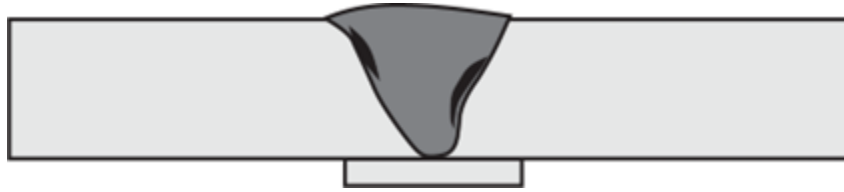


Figure 9 Slag inclusion (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

In metal arc welding, slag formation occurs particularly when using coated electrodes or fluxes. The stirring action of the arc can force the slag into the molten metal or it can be pushed ahead of the arc and then be covered over by the weld metal. Because it is less dense than molten metal, slag tends to rise to the surface of the puddle, where it can be chipped away when the weld is cooled.

Several factors can prevent the release of slag from the weld metal, including:

- High viscosity of the weld metal
- Rapid cooling
- Too low a temperature
- Incorrect manipulation of the electrode
- Undercut on previous passes

Slag inclusions can generally be prevented by preparing the weld correctly before each bead is deposited, making sure to correct the contour so that the arc can penetrate the joint completely and making sure all slag is cleaned from the surface of the previous bead. You can help to promote the release of slag by ensuring that the weld metal becomes hot enough to reduce its viscosity (thickness) and by pre- and post-heating to slow down the cooling process.

Cracking

Cracks are considered the most dangerous weld defects. They occur because of stresses that exceed the ultimate strength of the metal. **Cracking** that occurs shortly after the weld metal has been deposited and is just beginning to solidify is termed “**hot cracking**.” Some metals, especially the high alloy steels and other high-temperature alloys, are particularly susceptible to hot cracking. Cracking that occurs later, as the metal is approaching room temperature or after the weld has cooled completely is termed “cold cracking.” Cold cracking is much less common than hot cracking.

External Cracks

Cracking that is visible or external usually occurs in the weld metal (Figure 10). External cracks may run across the face of the metal and sometimes extend into the base metal. These are known as transverse cracks. Longitudinal cracks run lengthways along the weld, usually down the centre of the weld deposit. Crater cracks form in the centre of the crater and may become a starting point for longitudinal cracking. Crater cracks are usually the result of interruptions in the welding procedure.

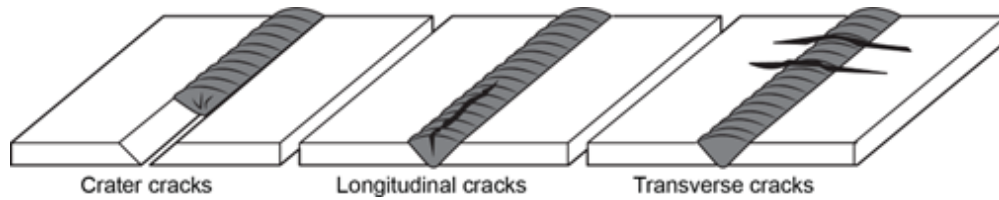


Figure 10 Visible cracks (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

External cracks most often are caused by too much restraint on the joint, too rapid cooling (particularly on hardenable and brittle metals), too little deposit on weld passes, and by incorrect electrode selection. External cracks may also be caused by other defects such as porosity, lack of penetration, slag inclusion and incomplete fusion. By increasing the thickness of the deposit on the first bead, decreasing the speed of travel to allow more weld metal to build up, and correcting pre- and post-heat treatments, most cracking can be avoided.

Internal Cracks

Internal cracks usually occur within the heat-affected zone of the base metal (Figure 11). Underbead cracking (a type of internal crack) occurs almost exclusively in steel and is associated with the use of low-hydrogen electrodes. Hairline cracks at the toe of the weld are caused by hot cracking in (or near) the fusion zone of weld and base metal.

Internal cracks are found chiefly in metals that have been hardened and that are fairly brittle. They are often associated with other weld faults such as undercutting, lack of fusion, incomplete penetration and slag inclusions.

Internal cracking can be prevented by the use of low-hydrogen electrodes, correct pre- and post- heating procedures, and careful attention to correct fit-up and welding procedures.

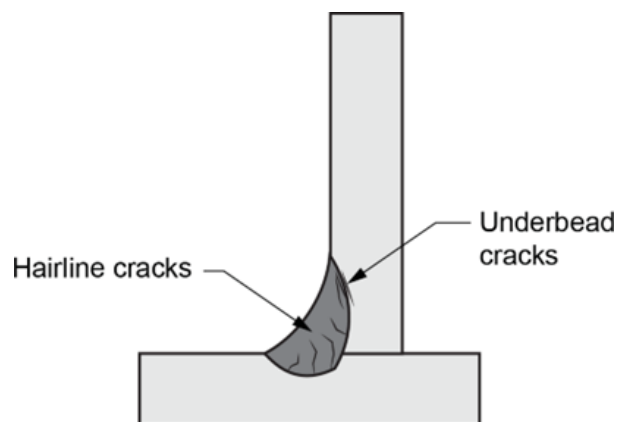


Figure 11 Internal cracks (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Distortion and Stress

One of the primary welding problems is the control of **distortion** and **residual stresses** that can occur in metal as it is heated and cooled during the welding process. Distortion refers to a change in shape of the weld, while residual stress refers to the buildup of internal stresses within either the weld or parent metal. Excessive distortion may result in a weld that exceeds dimensional tolerances, while excessive stress may cause weld cracking.

The underlying cause of both conditions is the characteristic of metals to expand (become larger) when heated and to contract (become smaller) when cooled. If metals are allowed to expand and contract freely (with no restraint) neither distortion nor residual stress is likely to occur. If the metal is restrained in a way that prevents free expansion and contraction (as is the case with weldments), distortion and the buildup of internal stresses can develop.

An example of this can be seen in the butt joints shown in Figure 12. When heat is applied to the joint, the metal in the weld area expands but is restrained by the surrounding cooler metal. The heated metal must expand upward in the unrestrained direction. Upon cooling, this displaced metal contracts, pulling in the surrounding metal across the width. This pulling force causes the edges of the weldment to bow upward, resulting in distortion.

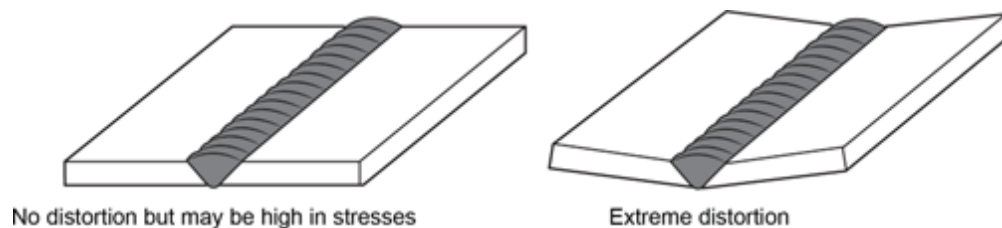


Figure 12 Distortion in a butt joint (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

If, however, the edges of the weldment had been rigidly restrained to prevent movement, there would be little evidence of distortion, but the likelihood of residual stresses would be very high.

The susceptibility of a metal to distortion depends on its mechanical and physical properties. High- alloy steels are more prone to distortion than mild steels, and larger welds generally undergo more distortion than smaller welds.

Distortion Control

Methods used to minimize or eliminate distortion include:

- avoid over-welding
- deposit the greatest amount of weld metal in the shortest time
- distribute the heat input as uniformly as possible
- use mechanical methods
- preheat and post-heat when necessary

Avoid Over-Welding

Use the smallest permissible size on fillet welds and, where possible, use intermittent rather than continuous welds. On butt joints, select a joint design that uses a minimum of weld metal. A U-joint preparation is preferable to a vee preparation (Figure 13). If a single vee preparation is required, bevel to achieve the smallest permissible included angle.

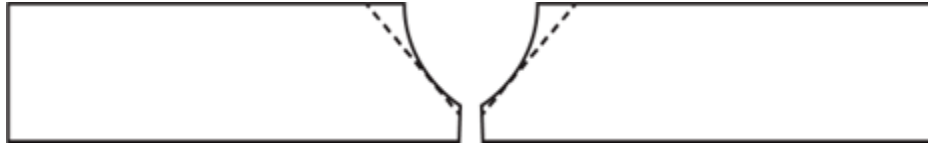


Figure 13 U-joint uses less weld metal (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Deposit the Greatest Amount of Weld Metal in the Shortest Time

The slower the rate of welding, the more time there will be for the heat to spread ahead of the welding point. This diffusion of heat input greatly increases the chances of distortions, so a high rate of travel is usually recommended on joints that are susceptible to distortion.

Wherever possible, try to weld in the flat position and use electrodes as large as possible for the particular joint. Iron powder electrodes are particularly good as they have a high deposition rate.

On multi-pass welds, apply as few passes as possible to complete the joint. Many small passes cause more distortion than a few large passes. This is particularly true for welds that may be subject to transverse shrinkage. For welds prone to longitudinal distortion, the reverse is often the case, and the correct technique is to use multiple passes, each having a small deposit.

Distribute Heat Input as Uniformly as Possible

The rate of heating and cooling varies within the joint depending on how close the metal is to the point of welding. Expansion and contraction will not be uniform, further complicating the incidence of distortion. Behind the welding point, the metal is cooling and contracting. In front, the metal is heating and expanding. By maintaining a high rate of travel, the differences in heat input can be minimized, as shown in Figure 14.

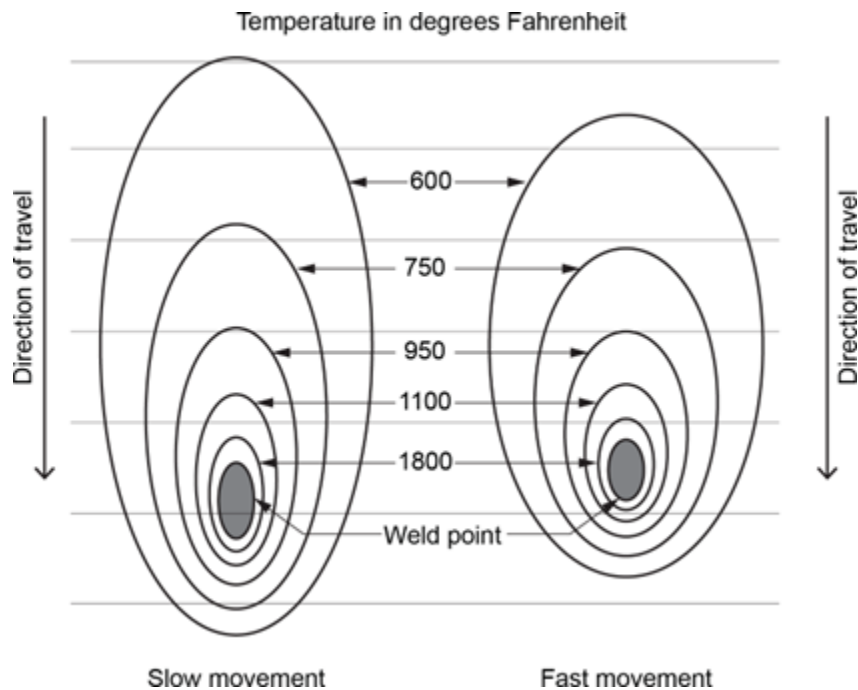


Figure 14 Travel speed and heat input (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Other techniques to keep the heat input as uniform as possible include intermittent welding sequences, back-step sequences, skip sequences, and the starting of a weld at a distance from the end of the joint. These methods break up the weld into short sections and help to control distortion and the buildup of residual stresses. The principle is that the shrinkage set up by one weld is counteracted by the shrinkage forces in subsequent welds.

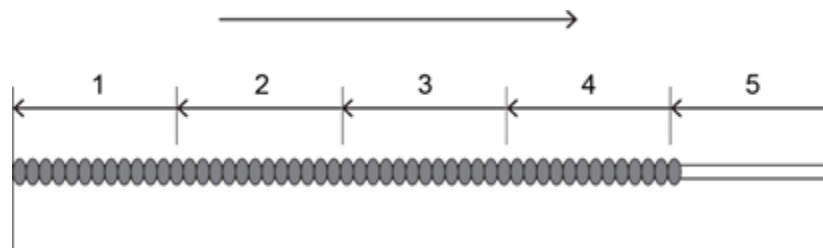


Figure 15 Back stepping (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

In the back step sequence, the weld begins a short distance from the end, with the direction of travel toward that end (Figure 15). The second deposit is then begun the same distance in from the first deposit and runs into the first deposit. The third deposit runs into the second and so on along the seam.

With skip welding, weld deposits are applied incrementally on each side of the centre of the seam. The first weld is made at the beginning of the joint. A section is skipped, and the second weld is applied further down the seam. Sometimes the weld starts at the centre and the weld builds back from the centre, alternating from end to end (Figure 16).

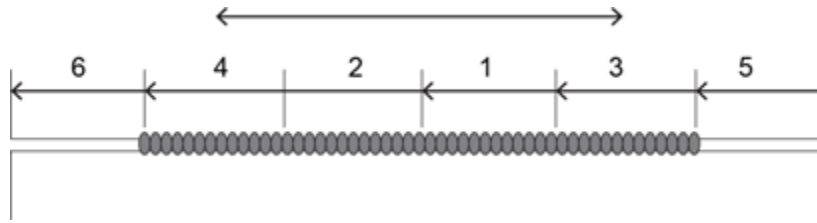


Figure 16 Skip welding (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

On long seams, starting the weld a short distance in from the end controls longitudinal distortion. The first weld is applied back toward the end of the joint, then the main weld picks up from the starting point of the first weld and continues to the other end (Figure 17).

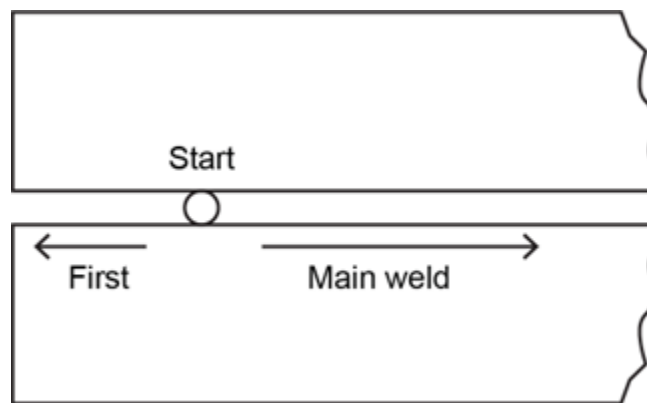


Figure 17 Technique for long seams (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

On large sections of plating, the weld should begin at a central point and proceed outward, as shown in Figure 18. The aim is to maintain a welding sequence that is more or less symmetrical around the centre.

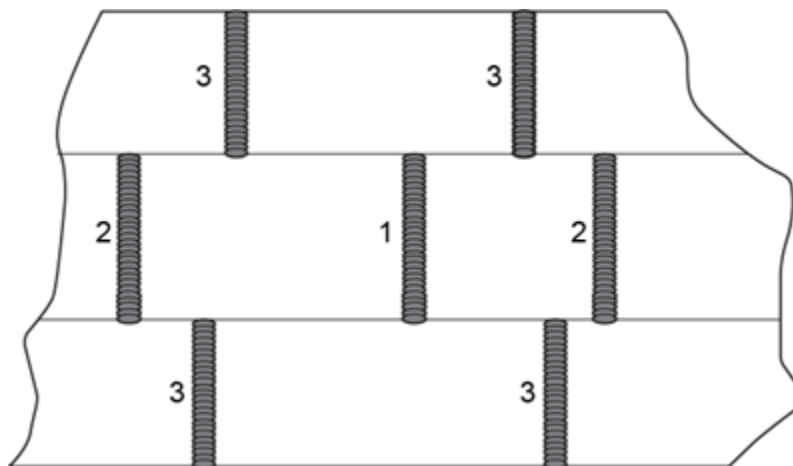


Figure 18 Technique for plating (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Use Mechanical Methods

A variety of mechanical methods can minimize distortion including pre-bending, clamping and pre-spacing.

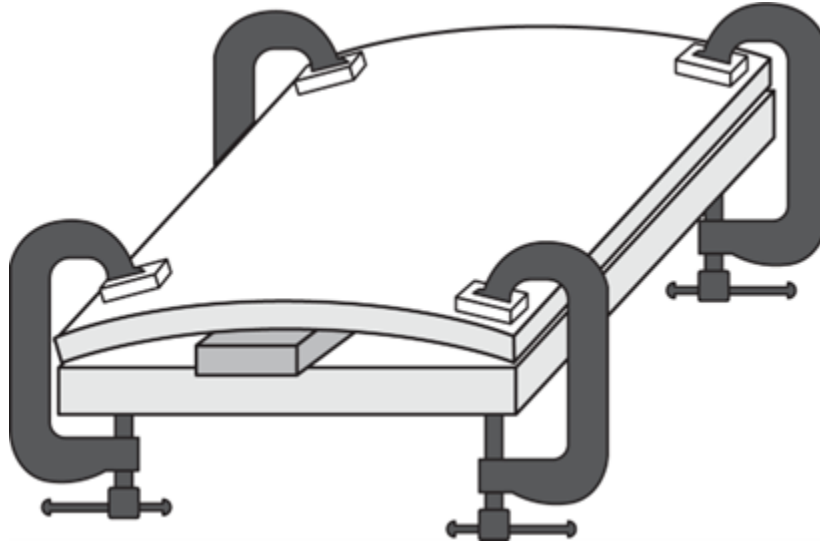


Figure 19 Pre-bending (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

A weldment can be pre-bent and restrained through the use of clamps to compensate for warping in the other direction (Figure 19). Once the clamps are removed, shrinkage forces will pull the plate back to the desired alignment. The clamps must be spaced and aligned carefully to avoid the buildup of internal stresses.

Figure 20 shows the pre-spacing or offsetting of parts to be welded. Pre-spacing, like pre-bending, compensates for the distortion that will occur when the completed joint shrinks. As shrinking occurs, the vertical member on the tee joint will be pulled into correct (90°) alignment. Likewise, the two members of the butt joint will also be drawn upward to become properly aligned.

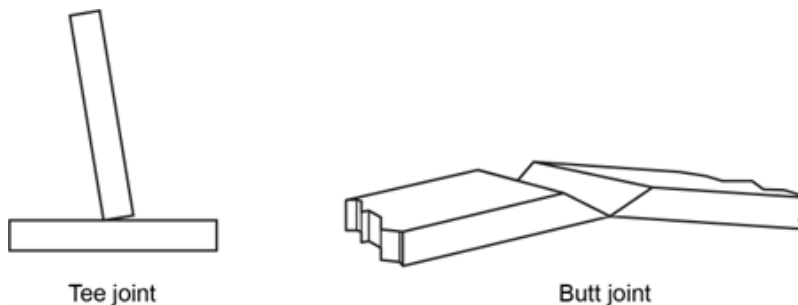


Figure 20 Offsetting (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Pre-Heat and Post-Heat When Necessary

Pre- and post-heat techniques play an important part in controlling the buildup of internal stresses and distortion.

Preheating helps to distribute the expansion of the metal evenly throughout the weldment. Entire sections of the weldment may require preheating or, in some cases, preheating may be necessary only on specific sections (Figure 21). Preheating techniques require considerable care to ensure that heat is distributed uniformly throughout the metal and the structure is allowed to cool slowly.

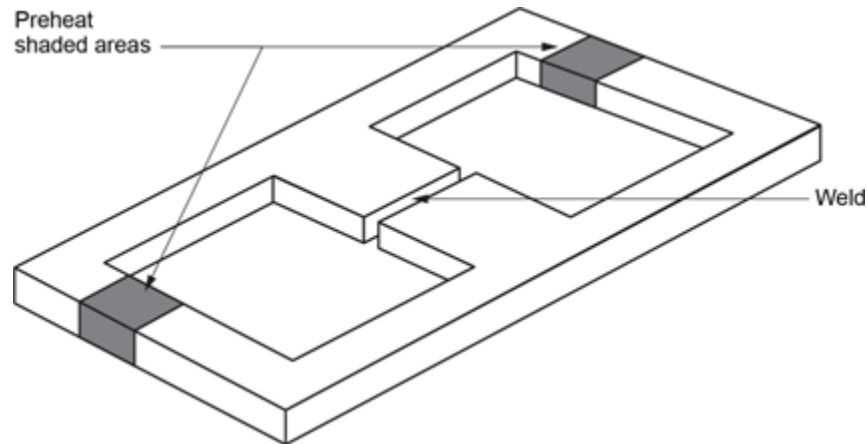


Figure 21 Preheating on specific sections (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Post-heating relieves residual stresses after the weld is completed. Heat treatments become increasingly important as you weld alloy steel, cast iron and other non-ferrous metals.



Self-Test B-6.4: Use Arc Welding Equipment

Complete Self-Test 6.4 and check your answers.

If you are using a printed copy, please find Self-Test A-6.4 and Answer Key in the Appendix at the end. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.



An interactive H5P element has been excluded from this version of the text. You can view it online here:
<https://b-handmeasuringtools-bcplumbingapprl1.pressbooks.tru.ca/?p=3050#h5p-21> (<https://b-handmeasuringtools-bcplumbingapprl1.pressbooks.tru.ca/?p=3050#h5p-21>)

References

- BC Industry Training Authority. (2019). *Piping trades apprenticeship program: Use Tools and Equipment—Level 1 harmonized* [Binder]. Crown Publications, Queen's Printer for British Columbia. https://www.crownpub.bc.ca/Product/Details/7960000261_S
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-5: Use welding equipment (Steamfitter)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-5: Use cutting, brazing and soldering equipment (Plumber)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-6: Use oxy-fuel cutting equipment (Plumber)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-6: Use soldering and brazing equipment (Steamfitter)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-7: Use oxy-fuel equipment (Steamfitter)*. Crown Publications, Queen's Printer for British Columbia.
- Industry Training Authority. (2019). *Piping trades apprenticeship program: Level 1—Competency B-7: Use welding equipment (Plumber)*. Crown Publications, Queen's Printer for British Columbia.

Media Attributions

All figures are sourced from Industry Training Authority (2019) and/or Camosun College (2019) and are used under the Creative Commons Attribution 4.0 (CC BY 4.0 (<https://creativecommons.org/licenses/by/4.0/>)) licence unless otherwise noted. Images copyrighted by the BC Industry Training Authority are licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 (CC BY-NC-SA 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)) licence.

Self-Test B-6.1: Describe Safety Requirements and Precautions for Arc Welding

Complete Self-Test B-6.1 and check your answers.

1. What is the first rule to remember when dealing with victims of electrical shock?
 - a. Pry or pull them loose with a non-conductive material
 - b. Avoid touching the victim if he or she is still in contact with the source of power
 - c. Send someone else to disconnect the power source
 - d. Send for the first-aid attendant
2. Which of the following best describes storage of electrodes?
 - a. Metal container
 - b. Neat pile on the workbench
 - c. Wooden container
 - d. Neat pile on the floor
3. What should you do if you inspect your welding cables prior to welding and find breaks in the insulation?
 - a. Ignore them
 - b. Replace the cable before work
 - c. Repair them with proper tape
 - d. Flag them for repair after work
4. When should all troubleshooting and maintenance of welding machines must be done?
 - a. Circuits show a line drop condition
 - b. Circuit is disconnected and locked out
 - c. Machine is not under load
 - d. Circuits are open and unplugged
5. What is the recommended minimum distance from which the electric arc should be seen by the naked eye?
 - a. 8 m (26')
 - b. 10 m (33')
 - c. 12 m (40')
 - d. 14 m (46')
6. When arc welding, what eyewear must you use?
 - a. Dark shaded sun glasses
 - b. Welding goggles with filter lens
 - c. A welder's helmet with filter lens
 - d. Flash goggles
7. Lenses come in numbered shades. Which would you use for a higher current setting?
 - a. No. 10
 - b. No. 12
8. Which of the following best describes the protective clothing to be worn for arc welding?
 - a. Dark
 - b. Light
 - c. Neutral
 - d. Colours is not significant

9. Toxic fumes that result from welding are always identifiable by smell.
- a. True
 - b. False
10. When your welding machine is on but you have finished welding, what must you do first?
- a. Remove your gloves and helmet
 - b. Remove the electrode from its holder
 - c. Disconnect the ground cable
 - d. Disconnect the electrode cable)

Answer Key: Self-Test B-6.1 is on the next page.

Answer Key: Self-Test B-6.1

1. b. Avoid touching the victim if he or she is still in contact with the source of power
2. a. Metal container
3. c. Repair them with proper tape
4. b. Circuit is disconnected and locked out
5. c. 12 m (40')
6. b. Welding goggles with filter lens
7. b. No.12
8. a. Dark
9. b. False
10. b. Remove the electrode from its holder

Self-Test B-6.2: Identify Types of Welds, Positions, Joints and Symbols

Complete Self-Test B-6.2 and check your answers.

1. There are five basic joint designs used in welding. The lap, tee, corner and edge are four of them. Name the fifth joint design.
 - a. Plug
 - b. Vee
 - c. Bevel
 - d. Butt
2. Which type of joint is shown in Figure 1?



Figure 1 Image for question 2

3. In order for lap and tee joints to support heavy or fluctuating loads, they need to be
 - a. Welded from both sides
 - b. Welded on only one side
 - c. Single beveled
 - d. Double beveled
4. Which of the following is the most commonly selected corner joint?
 - a. Half open
 - b. Closed
 - c. Flanged
 - d. Open
5. When are edge joints generally used?
 - a. Sheet metal
 - b. Pipe
 - c. Heavy gauge metal
 - d. Castings
6. Which edge preparation is used on the tee joint in Figure 2?

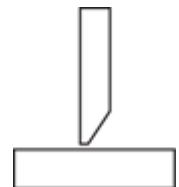


Figure 2 Image for Question 6

7. The butt joint shown in Figure 3 is a
 - a. Single U
 - b. Single J
 - c. Double U
 - d. Double J



Figure 3 Image for question 7

8. Which type of weld is most commonly used to weld lap, tee and corner joints?
 - a. Groove weld
 - b. Bead weld
 - c. Fillet weld
 - d. Plug weld
9. Groove welds typically are what kind of joints?
 - a. Tee joints
 - b. Lap joints
 - c. Edge joints
 - d. Butt joints
10. What typically determines the size of groove welds?
 - a. Width between toes
 - b. Depth of penetration
 - c. Included angle
 - d. Root radius
11. In Figure 4, A indicates the
 - a. Root landing
 - b. Root opening
 - c. Thickness
 - d. Bevel angle
12. In Figure 4, B indicates the
 - a. Included angle
 - b. Root landing
 - c. Thickness
 - d. Root radius
13. In Figure 4, D indicates the
 - a. Root landing
 - b. Included angle
 - c. Bevel angle
 - d. Root opening, gap
14. In what position would one weld a 1G?
 - a. Fillet weld in the vertical position
 - b. Groove weld in the flat position
 - c. Gillet weld in the horizontal position
 - d. Groove weld in the vertical position
15. In what position would one weld a 2G?
 - a. A horizontal fillet weld
 - b. A vertical groove weld
 - c. A vertical fillet weld
 - d. A horizontal groove weld
16. Which weld position is shown in Figure 5?

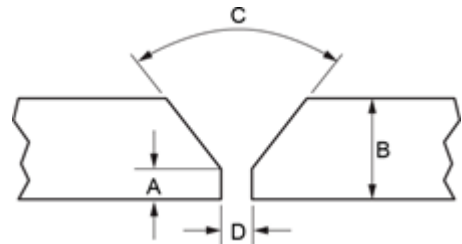


Figure 4 Image for Question 12

- a. Flat
- b. Horizontal
- c. Vertical
- d. Overhead

Answer Key: Self-Test B-6.2 is on the next page.

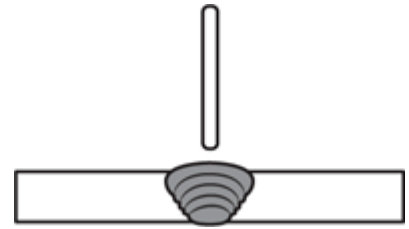


Figure 5 Image for Question 16

Answer Key: Self-Test B-6.2

1. d. Butt
2. d. Lap
3. a. Welded from both sides
4. d. Open
5. a. Sheet metal
6. b. Single bevel
7. a. Single U
8. c. Fillet weld
9. d. Butt joints
10. b. Depth of penetration
11. a. Root landing
12. c. Thickness
13. d. Root opening, gap
14. b. Groove weld in the flat position
15. d. A horizontal groove weld
16. a. Flat

Self-Test B-6.3: Describe the Arc Welding Process and Equipment

Complete Self-Test B-6.3 and check your answers.

1. Which of the following terms describes the mixture of melted electrode and melted parent metal created by the welding current flowing through the electrode and across the arc?
 - a. SMAW
 - b. The weld deposit
 - c. The short circuit
 - d. The workpiece
2. Which term describes the welding machine turned on but no arc established?
 - a. Ohm's Law
 - b. Short-circuit voltage
 - c. Closed-circuit voltage
 - d. Open-circuit voltage
3. In shielded metal arc welding, metals are fused by the heat from an electric arc that is maintained between the surface of the workpiece and which of the following electrodes?
 - a. Covered electrode
 - b. Bare electrode
 - c. Neutral electrode
 - d. Carbon electrode
4. In SMAW, what purpose does the electrode's flux coating serve?
 - a. Keep the arc stable
 - b. Keep the arc concentrated on the weld
 - c. Provide the sheilding gases
 - d. All of the above
5. Which term describes the electrical pressure or voltage in a welding circuit after the arc has been struck?
 - a. Open-circuit voltage
 - b. Line voltage
 - c. Arc voltage
 - d. Electrode voltage
6. Which of the following is not a consideration when you select a polarity?
 - a. The type of coating material on the electrodes
 - b. The temperature of the workpiece
 - c. The welding position
 - d. The types of material to be welded
7. Which of the following best describes direct current?
 - a. Flows consistently from the positive to the negative pole
 - b. Flows first from the negative to the positive pole, and then from the positive to the negative pole
 - c. Flows consistently from the negative to the positive pole
 - d. Is more dangerous than alternating current
8. Besides the jaw type, what is the most common type of stinger?

- a. Spring type
 - b. Twist-head type
 - c. Clamp type
 - d. Jib type
9. What is the appropriate course of action if the cable connection to the electrode holder contains frayed or broken strands of wire?
- a. Repair the connection with electrical tape
 - b. Put the cable permanently out of service
 - c. Cut off the damaged end and make a new connection
 - d. Turn the cable end for end
10. What is a probable result of using an electrode with broken flux coating?
- a. Slag inclusions
 - b. Hard spots
 - c. Porosity
 - d. Lack of fusion
11. Which of the following electrodes need to be stored in an electrode oven?
- a. All mild steel electrodes
 - b. Low-hydrogen, hardsurfacing, and special alloy electrodes
 - c. Mild steel, low-hydrogen, and special alloy electrodes
 - d. Mild steel, hardsurfacing, and special alloy electrodes
12. Which of the following terms describe common portable grinders?
- a. Angel grinders
 - b. Bevel grinders
 - c. Curved grinders
 - d. Disk grinders
13. Which of the following PPE is required when using a portable grinder?
- a. Leather gloves
 - b. A fireproof apron
 - c. Eye protection
 - d. A hard hat

Answer Key: Self-Test B-6.3 is on the next page.

Answer Key: Self-Test B-6.3

1. a. SMAW
2. d. Open-circuit voltage
3. a. Covered electrode
4. d. All of the above
5. c. Arc voltage
6. b. The temperature of the workpiece
7. c. Flows consistently from the negative to the positive pole
8. b. Twist-head type
9. c. Cut off the damaged end and make a new connection
10. a. Slag inclusions
11. b. Low-hydrogen, hardsurfacing, and special alloy electrodes
12. a. Angle grinders
13. c. Eye protection

Self-Test B-6.4: Use Arc Welding Equipment

Complete Self-Test B-6.4 and check your answers.

- Which of the following best describes the amount of weld produced with 1" of electrode when correct speed is used?
 - 1"
 - 1 1/2"
 - 2"
 - 3"
- Which of the following best describes the correct angle for the electrode?
 - 20–30° off perpendicular in direction of travel
 - 20–30° off perpendicular away from direction of travel
 - Perpendicular to work
 - 45° off perpendicular in direction of travel
- What does a hissing sound during welding indicate?
 - Electrode too far from work
 - Electrode too close to work
 - Electrode ideal distance from work
 - Amperage is too high
- What is the most common cause of undersized welds?
 - Rate of travel that is too fast
 - Welding current that is too low
 - Incorrect polarity
 - Rate of travel that is too slow
- Which weld defect is shown in Figure 1?
 - Incomplete penetration
 - Cracking
 - Porosity
 - Undercut
- Which defect is shown in Figure 2?
 - Porosity
 - Cracking
 - Lack of fusion
 - Slag inclusion
- Which of the following is the major cause of incomplete penetration?
 - Incorrect joint design
 - Too small an electrode
 - Failure to heat the base metal
 - Rate of travel is too slow
- Which of the following suffers from hot cracking?
 - Mild steel
 - High-alloy steel



Figure 1 Image for Question 5



Figure 2 Image for Question 6

- c. Low-hydrogen electrodes
 - d. Joints that are cooled slowly
9. In which of the following conditions do crater cracks often occur?
- a. Current is too low
 - b. Electrode is defective
 - c. Welding has been interrupted
 - d. Base metal has been preheated
10. Which of the following actions will help prevent slag inclusion?
- a. Extending the arc length
 - b. Reducing the current setting
 - c. Using coated electrodes or fluxes
 - d. Cleaning all slag from the surface of the previous bead
11. Which of the following is the most common cause of undercut?
- a. Too little current
 - b. Too rapid cooling
 - c. Improper electrode manipulation
 - d. Improper cleaning of base metal
12. Which of the following is the most common cause of distortion?
- a. Porosity in the weld metal
 - b. Pre- and post-heat treatments
 - c. Hot cracking in the weld metal
 - d. Uneven expansion and contraction within a metal
13. Which of the following is a mechanical means of preventing distortion?
- a. Pre-bending
 - b. Multi-pass welding
 - c. Intermittent welding
 - d. Back-step sequences
14. Which of the following butt joint preparations is most prone to angular distortion?
- a. U-butt joint
 - b. Double vee joint
 - c. Square butt joint
 - d. Single vee butt joint
15. Which of the following terms describe a serious defect in which excess weld metal is deposited at the toe of the weld and is most often a sign of poor fusion between the weld and parent metal?
- a. Overlap
 - b. Porosity
 - c. Undercut
 - d. Distortion

Answer Key: Self-Test B-6.4 is on the next page.

Answer Key: Self-Test B-6.4

1. a. 1"
2. a. 20–30° off perpendicular in direction of travel
3. a. Electrode too far from work
4. a. Rate of travel that is too fast
5. c. Porosity
6. c. Lack of fusion
7. a. Incorrect joint design
8. b. High-alloy steel
9. c. Welding has been interrupted
10. d. Cleaning all slag from the surface of the previous bead
11. c. Improper electrode manipulation
12. d. Uneven expansion and contraction within a metal
13. a. Pre-bending
14. d. Single vee butt joint
15. a. Overlap

Version History

This page provides a record of changes made to this learning resource, Plumbing Apprenticeship Level 1, Block B (<https://b-handmeasuringtools-bcplumbingapprl1.pressbooks.tru.ca/>). Each update increases the version number by 0.1. The most recent version is reflected in the exported files for this resource.

Important Notice: This book contains content used with permission from Skilled Trades BC, Trades Training BC, and various third-party contributors, with all third-party content identified and attributed throughout. To create your own version, you must obtain explicit permission from Skilled Trades BC and the respective third-party content owners.

If you identify an error in this resource, please report it using the TRU Open Education Resource Error Form.

Version	Date	Change	Details
1.0	May 2026	Plumbing Apprenticeship Level 1 Block B learning resource from STBC content converted to open and freely accessible digital platform and published at TRU.	

Plumbing Apprenticeship & Trade Resources in BC

A successful career in plumbing requires a strong foundation of skills, knowledge, and workplace safety awareness. Below are key resources to support plumbing apprentices in BC, including educational pathways, trade certifications, workplace safety guidelines, and mental health and wellness support.

Plumbing Apprenticeship & Certification Resources

- **SkilledTradesBC – Plumbing Apprenticeship** (<https://skilledtradesbc.ca/plumber>) – Overview of plumbing training, certification requirements, and apprenticeship pathways in British Columbia.
- **Red Seal Program – Plumber** (<https://www.red-seal.ca/eng/trades/plumbers/overview.shtml>) – National certification program with exam prep guides and trade mobility information.
- **BC Building Codes & Standards** (<https://www.bccodes.ca/>) – Official building and plumbing codes for British Columbia.

Workplace Safety & Regulations

- **WorkSafeBC** (<https://www.worksafebc.com/en>) – Essential safety resources for plumbers, including:
 - Health & Safety – WorkSafeBC (<https://www.worksafebc.com/en/health-safety>)
 - Report Unsafe Working Conditions (<https://www.worksafebc.com/en/contact-us/departments-and-services/health-safety-prevention>)
 - Report a Workplace Injury or Disease (<https://www.worksafebc.com/en/claims/report-workplace-injury-illness>)
 - Submit a Notice of Project Form (<https://www.worksafebc.com/en/for-employers/just-for-you/submit-notice-project>)
 - Get Health and Safety Resources (Videos, Posters, Publications, and More) (<https://www.worksafebc.com/en/resources-health-safety>)
 - Search the OHS Regulations (and Related Materials) (<https://www.worksafebc.com/en/law-policy/occupational-health-safety/searchable-ohs-regulation>)
 - Conduct an Incident Investigation (<https://www.worksafebc.com/en/health-safety/create-manage/incident-investigations/conducting-employer-investigation>)
- **CCOHS: OHS Answers Fact Sheets – Plumber** (https://www.ccohs.ca/oshanswers/occup_workplace/plumber.html) – Safety guidelines and best practices for plumbers in various work environments.

Financial Supports

- **Financial Support (SkilledTradesBC)** (<https://skilledtradesbc.ca/financial-support>) – Information about grants, tax credits, Canada apprentice loans, employment insurance, and the Indigenous Skills and Employment Training

(ISET) program.

- **StudentAidBC** (<https://studentaidbc.ca/>) – Complete post-secondary education through student loans, grants, and scholarships. There is also programs that help with loan repayment.
- **WorkBC (Government of BC)** (<https://www.workbc.ca/find-loans-and-grants/students-and-adult-learners/services-apprentices-and-employers>) – Services for apprentices and employers.

Mental Health & Wellness Support

- **HealthLink BC – Mental Health and Substance Use** (<https://www.healthlinkbc.ca/mental-health-and-substance-use>) – HealthLink BC resources for mental health and wellness support.
- **Here2Talk** (<https://here2talk.ca/>) – Free and confidential counseling services available to all post-secondary students registered at a BC school.
- **Help Starts Here** (<https://helpstartshere.gov.bc.ca/>) – A database with over 2,500 listings of services related to mental health and substance use supports.
- **Hope for Wellness Helpline** (<https://www.hopeforwellness.ca/>) – 24/7 online chat and phone line with experienced and culturally competent counselors available to all Indigenous people in Canada.
 - First Nations Health Authority Mental Health Supports Info Sheet [PDF] (<https://www.fnha.ca/Documents/FNHA-mental-health-and-wellness-supports-for-indigenous-people.pdf>) by First Nations health Authority – List of culturally safe services for Indigenous people.
- **HeretoHelp – BC** (<https://www.heretohelp.bc.ca/>) – Mental health resources, including videos, articles, and support services in BC.
- **BC Construction Industry Rehabilitation Plan** (<https://www.constructionrehabplan.com/>) – Mental health and substance use services for CLRA and BCBT members and their families.
- **Virtual Mental Health Supports (Government of BC)** (<https://www2.gov.bc.ca/gov/content/health/managing-your-health/mental-health-substance-use/virtual-mental-health-supports>) – Virtual services are available for British Columbians who are experiencing anxiety, depression, or other mental health challenges.

Crisis Support

- **Interior Crisis Line Network** – Call 1-888-353-2273 (tel:+1-888-353-2273) for 24/7 emotional support, crisis intervention, and community resource information.
- **Talk Suicide Chat Service** (<https://talksuicide.ca/>) – An alternative if calling is difficult; available for crisis intervention.
- **310Mental Health Support** – Call 250-310-6789 (tel:+1-250-310-6789) for emotional support, information, and resources specific to mental health.
- **1-800-SUICIDE** – Call 1-800-784-2433 (tel:+1-800-784-2433) if you are experiencing feelings of distress or despair, including thoughts of suicide.
- **Opioid Treatment Access Line** – Call 1-833-804-8111 (tel:+1-833-804-8111) between 9 am and 4 pm to connect with a doctor, nurse, or healthcare worker who can prescribe opioid treatment medication that same day.
- **KUU-US Crisis Response Service** – Call 1-800-588-8717 (tel:+1-800-588-8717) for culturally-aware crisis support for Indigenous peoples in BC.
- **Alcohol and Drug Information and Referral Service** – Call 1-800-663-1441 (tel:+1-800-663-1441) to find resources and support.



Emergency Services — For life-threatening situations, call 911 or visit your nearest emergency department.