SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING

Co-funded by the Erasmus+ Programme of the European Union

Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

CU 01: DED-Arc

Session 3.4 TIG – DED System & Process

Prepared by: Michael Moore & Chris Ellis 2023

FOR SAM PILOT ATTENDEES AND TRAINERS ONLY

MM17,21

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Contents

- Introduction to TIG welding (RECAP)
- More detail on TIG welding process
- Common TIG welding defects
- TIG welding applications

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Overview of typical TIG welding system hardware

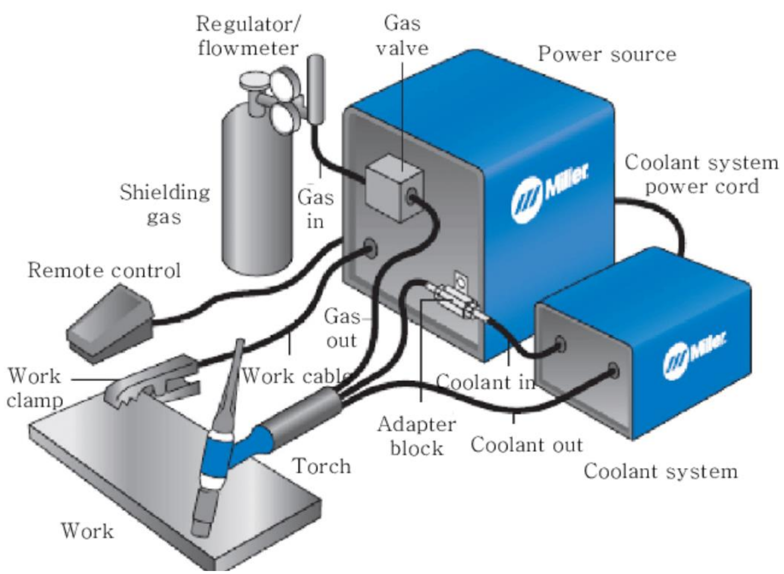
TIG welding equipment commonly consists of:

I. **TIG torch-** that is the tool containing the non-consumable electrode

II. **Power source -** capable of providing the necessary welding current, can be AC or DC.

III. **Control unit -** enables welding current, arc initiation method and current type to be adjusted

IV. **Shielding gas cylinder -** with pressure control valve (regulator) and flowmeter.



Miller Welding

[Intro to TIG Welding- 3min Video]

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RECAP

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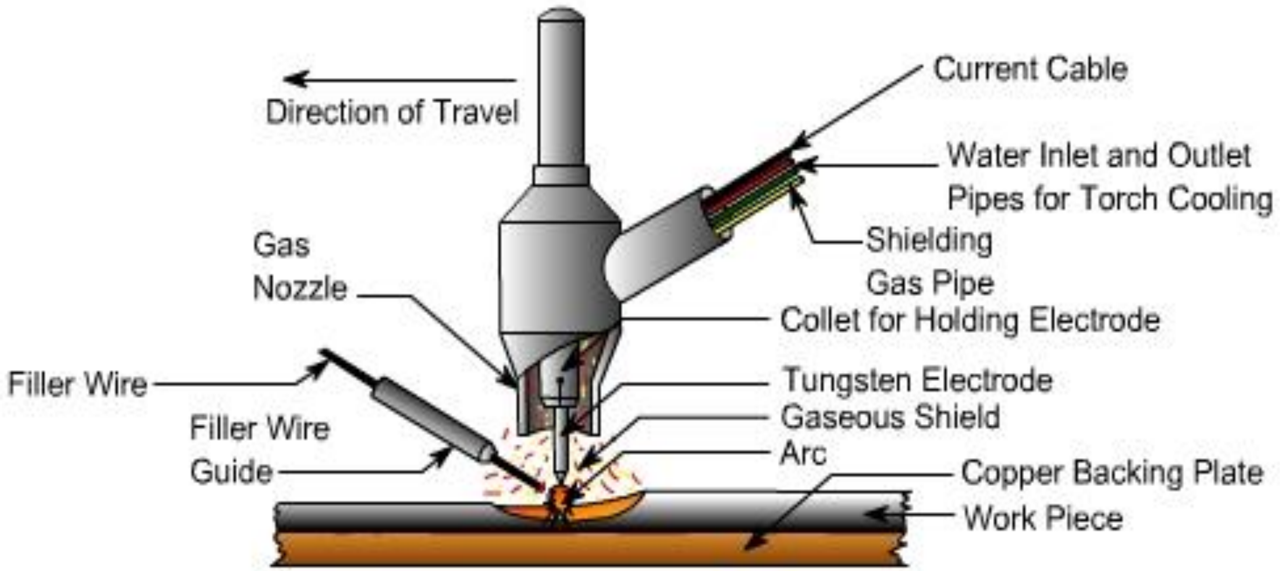
TIG welding head (torch)



Source: Miller Welding

Tungsten Inert Gas (TIG) - arc is generated between a non consumable tungsten electrode and the workpiece material.
Electrode and weld pool are shielded by inert gas,normally argon and helium

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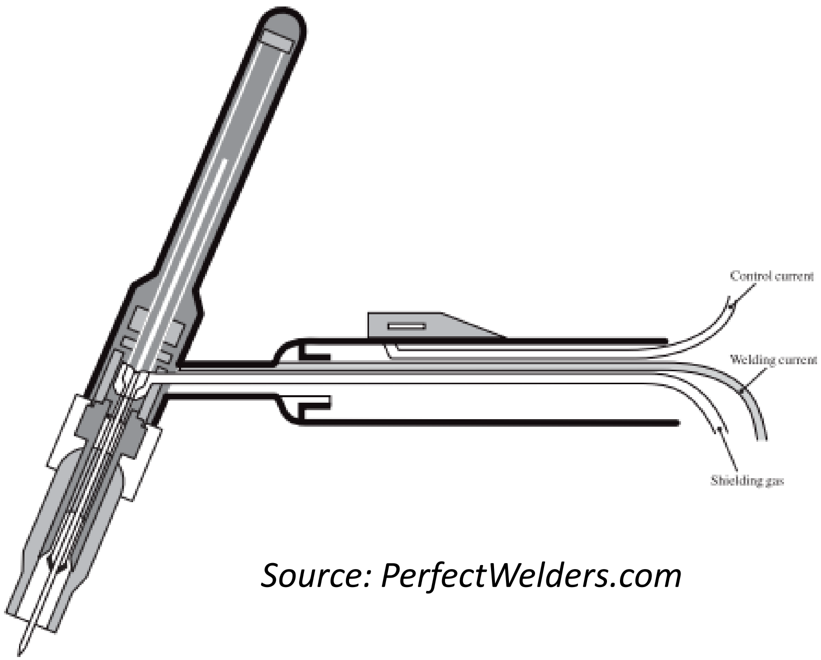
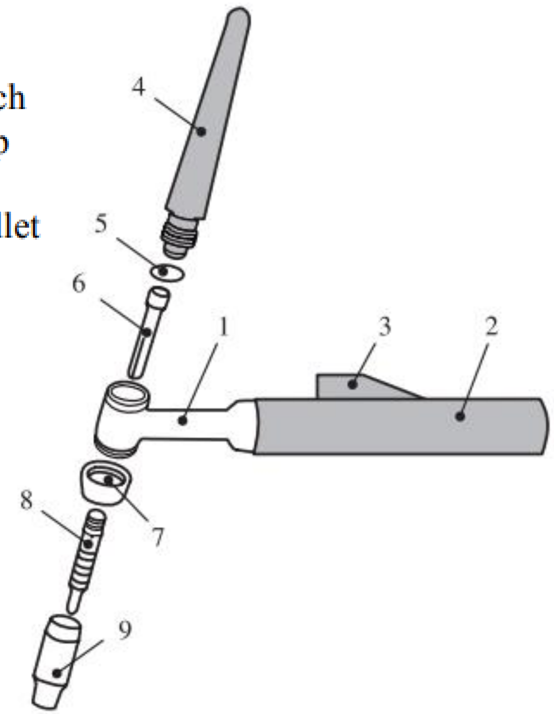
Inside of the TIG torch



Source: *PerfectWelders.com*

1. Torch head
2. Handle
3. Control switch
4. Electrode cap
5. Sealing ring
6. Electrode collet
7. Heat shield
8. Collet body
9. Gas nozzle



- Electrode collet grips electrode securely in correct position when cap is tightened
- Current transfer to electrode takes place very close to the tip
- Current amperage usually adjusted via control on torch or foot pedal

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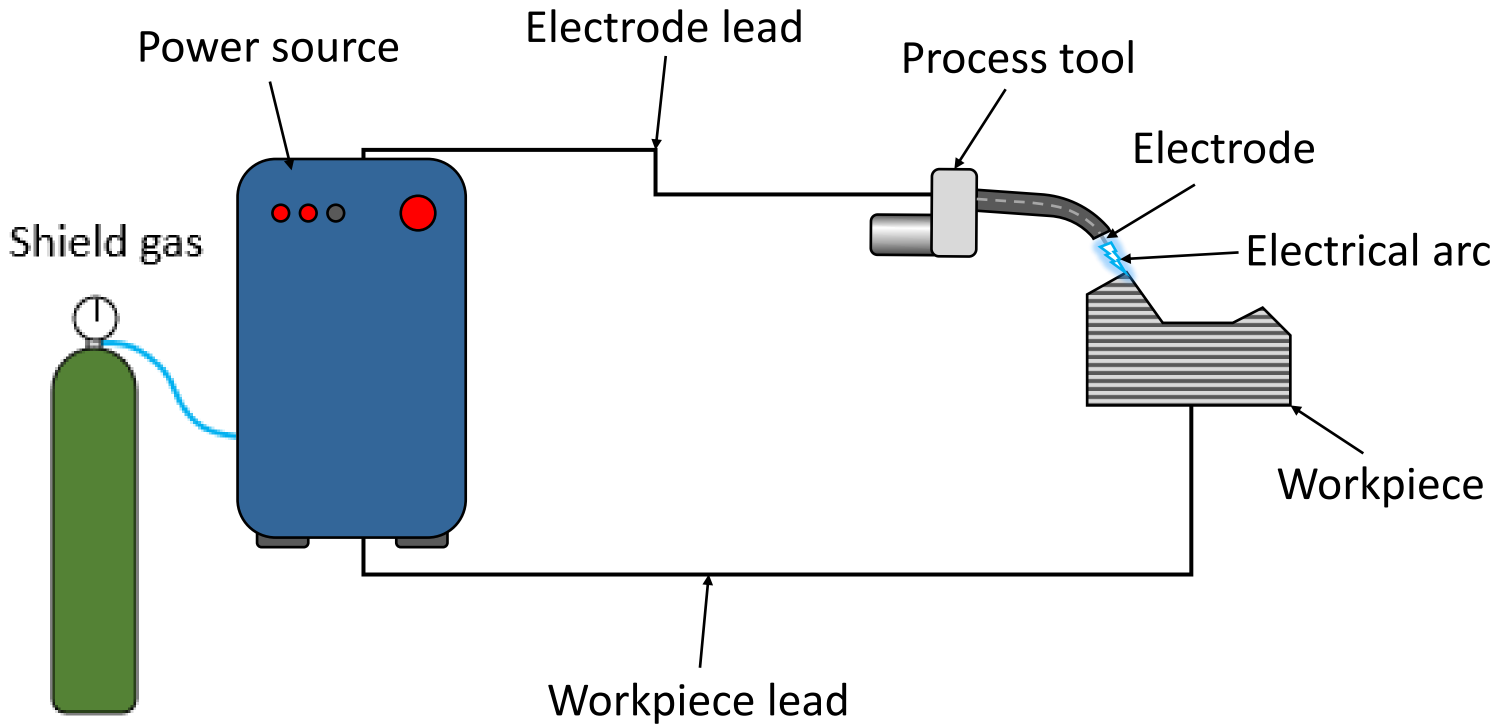
Welding system components



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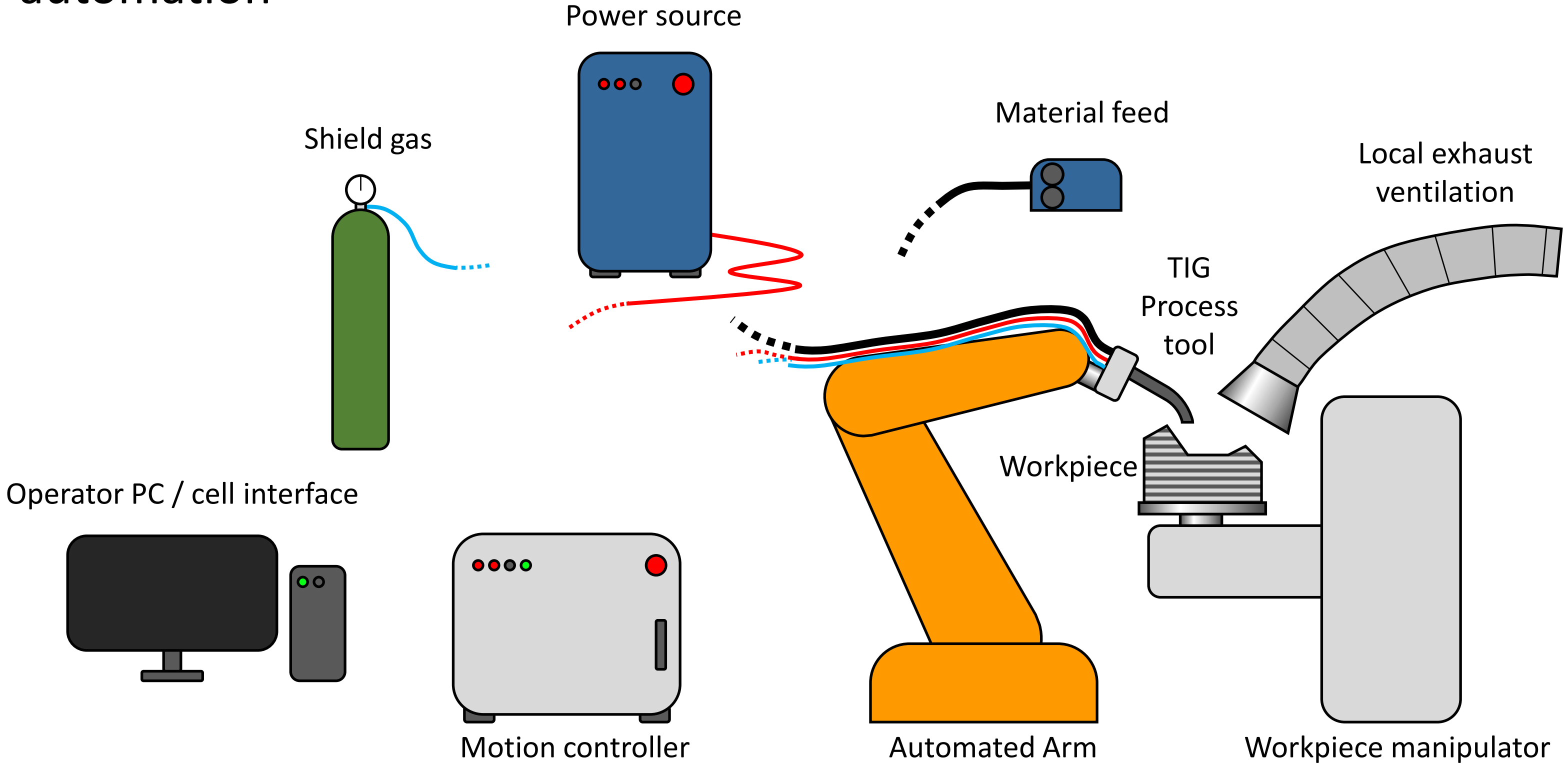
DED system components

[Intro to DED Welding- Video 3Mins]

Welding system
+ automation



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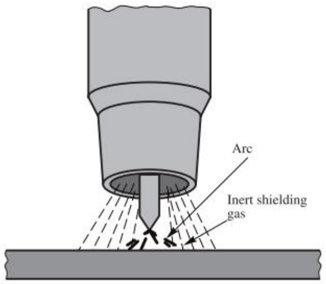
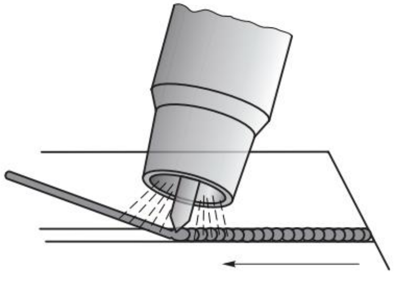
RECAP

TIG Welding

- Fusion energy produced by arc between workpiece and electrode.
- Electrode and weld pool are protected by an inert shielding gas
- TIG welding electrode is not consumed, unlike electrodes MIG/MAG and MMA
- Filler material is supplied from a separate wire (manually or driven feed)



TIG welding Principle



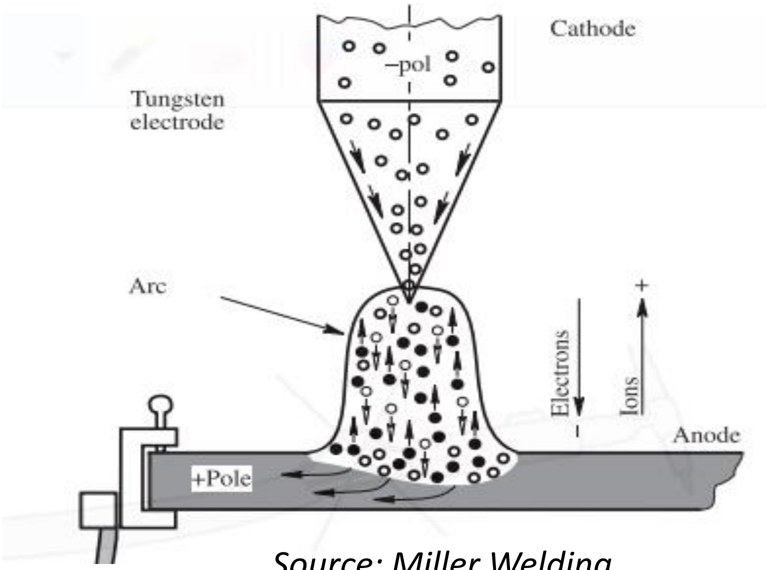
Feeding of filler material

Source: Miller Welding

More detail….

TIG Welding

- In DC TIG welding the electrode is usually connected to negative polarity and workpiece to positive polarity.
- Alternating Current – varies in a cyclic fashion
- When the arc is struck electrons migrate from the negative pole to the positive pole while the ions will travel in the opposite direction.
- In the arc there will therefore be a collision between the electron and the ions and this collision produces heat energy.



Source: Miller Welding

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Power Sources

Power sources typically fall into one of the following categories; **transformers, generators, rectifiers, and inverters;**

Transformers - Simple power supplies that take **mains AC power** supply, and outputs a **high AC amperage and low voltage**.

Rectifiers - Converts mains **AC to DC** output.

Inverters – Similar function to transformers, taking mains AC and outputting high current, low voltage AC. Inverters achieve this through the use of **electronic circuitry** rather than traditional transformers, and as such offer **greater control** through power output modulation and tuning for the welding application.

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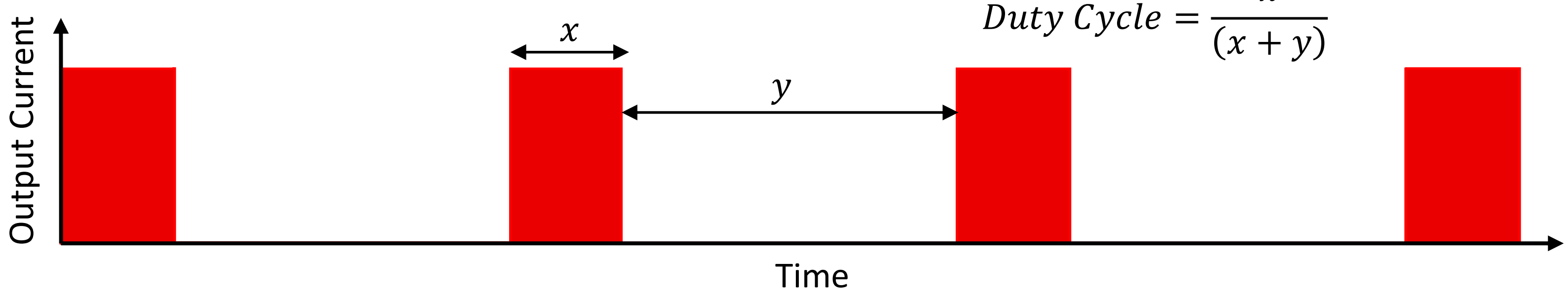
Process Tool – Duty Cycle

- Power source generates significant heat during operation
- Overheating prevents continuous operation
- System design (particularly cooling) determine the maximum duration of use (duty cycle)
- Duty cycle is the % of the total time which the unit can operate (ie if unit can only operate for 10 minutes before allowing to cool for 10min = 50% duty cycle)

Very important factor for automated welding processes including DED



$$Duty\ Cycle = \frac{x}{(x+y)}$$

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Selection of power source for TIG-DED

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Welding System Hardware

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R-Tech DC TIG welder 160A 230V

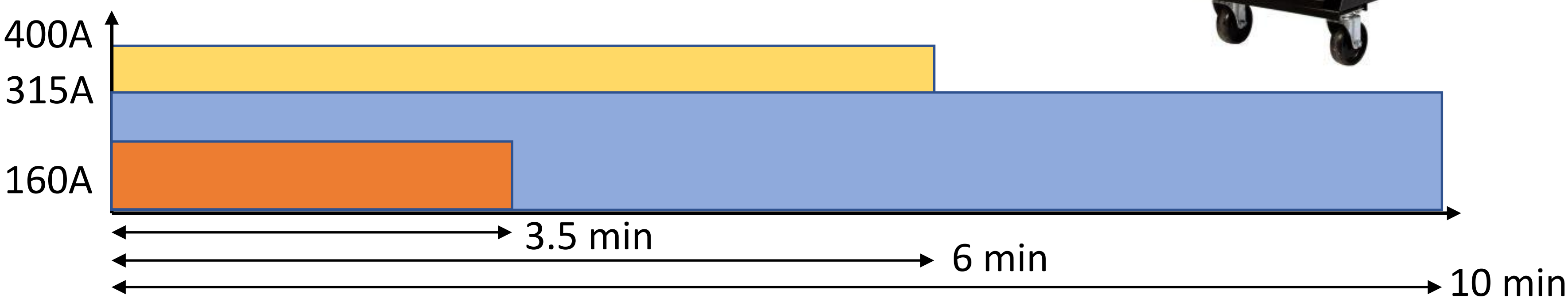
Duty cycle:
160A - 35%

Air cooled
cost: ~£500

R-Tech AC/DC TIG welder 400A 415V

Duty cycle:
400A - 60%
315A - 100%

Water cooled
Cost ~£2600



Despite the higher energy output the duty cycle for the water cooled unit is longer due in a major part to having superior cooling and electronic controls.

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Welding System Hardware

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R-Tech AC/DC TIG welder
400A 415V

Duty cycle:
400A - 60%
315A - 100%

Highest energy input into workpiece (crudely indicator of productivity) is running welder at highest sustainable rather than maximum current (after 8 minutes energy input is greater)

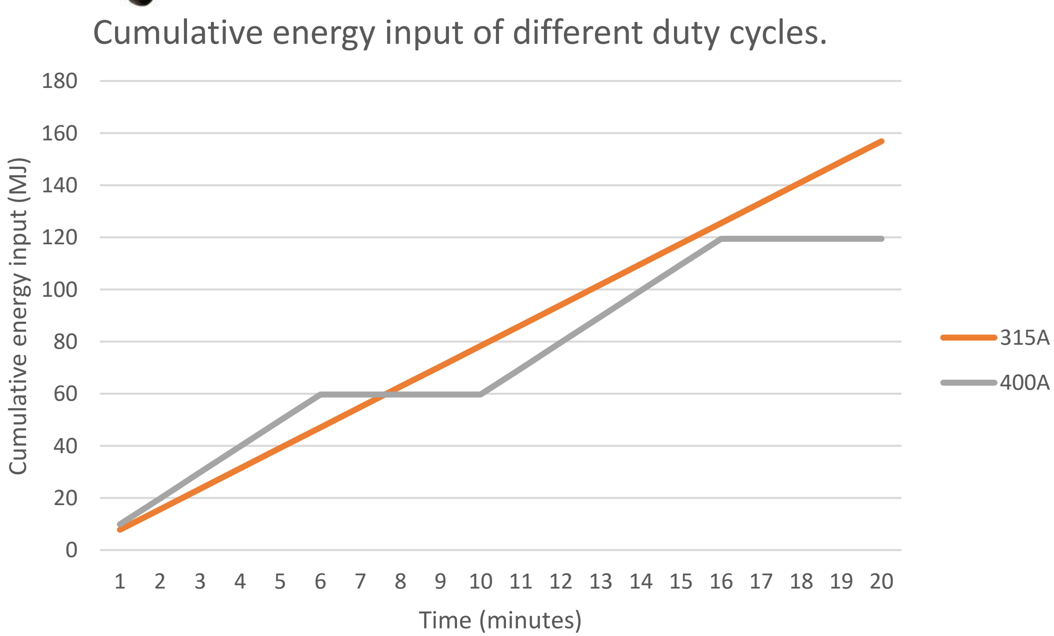

Chart does not consider issues such as restarting welds, restriking the arc and other issues with starting and stopping the welding process

However, some materials and thicknesses require the higher amperage, and many other considerations do go into power selection.

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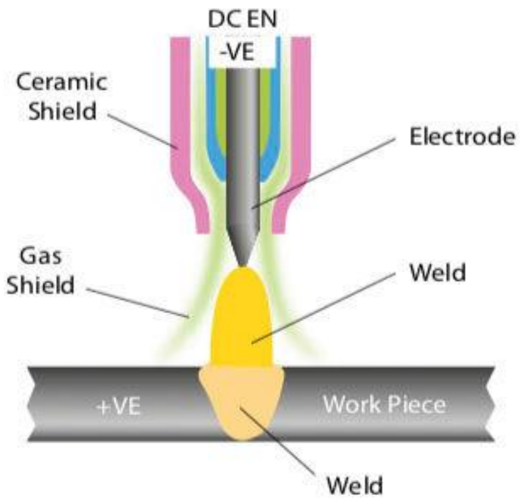
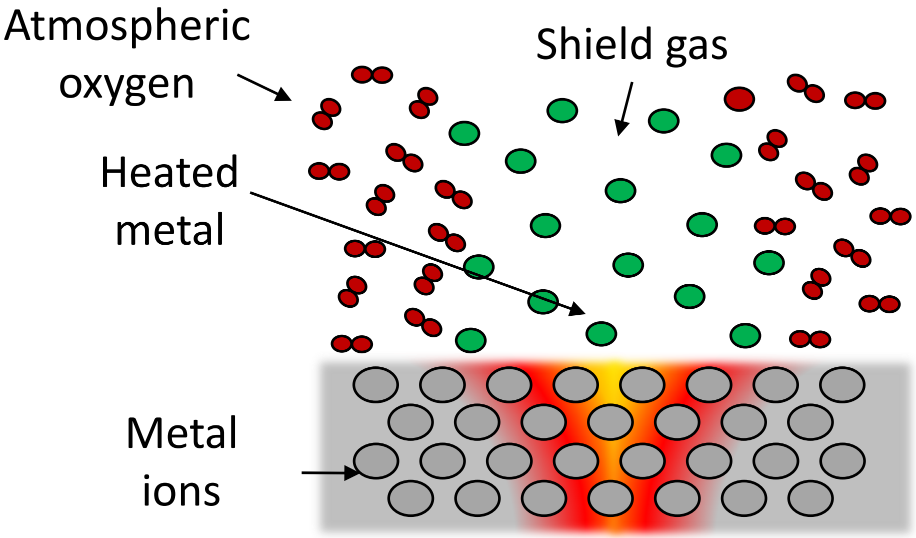
Shielding gas

Most metals bond with atmospheric oxygen to form metal oxides
Elevated temperature increases the rate of oxidation
Shielding gas has several functions including ;

- Displace atmospheric air so it will not combine with the weld pool and tungsten electrode
- Shielding gas also plays an important role in enabling the generation of the arc
- Provides cooling to torch and workpeice

For TIG welding two of the inert gases used are argon (Ar) and helium (He) of which argon is the more frequently used. The two inactive shielding gases can be mixed with each other or each of them mixed with a type of gas which has a reducing effect.





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More detail……

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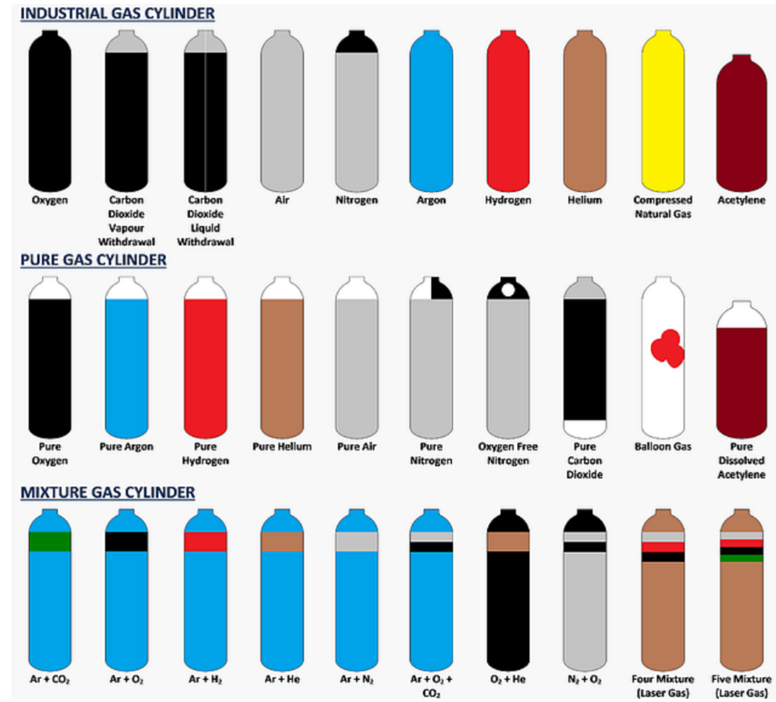
Gas bottle colours and welding gases

	Colour of the cylinder	Colour of the shoulder
Ar	Turquoise	Turquoise
Ar/H2	Turquoise	Red
Ar/He	Turquoise	Brown
He	Brown	Brown
N2/H2	Light grey	Red



http://www.wks.com.sg/user-info/cylinder-colour-chart/

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Gas and flow rate selection for TIG welding

	Non-alloyed and low-alloyed steels	Stainless steels	Nickel-alloyed	Copper-alloyed	Aluminium-alloyed
Ar	x	x	x	x	x
Ar/H2		x	x		
Ar/He			x	x	x
He				x	x

Nozzle Dia. (mm)	Gas flow (L/min)
6	4.7-6.6
8	5.2-7.0
10	5.6-7.5
13	8.0-9.4
16	8.0-9.4

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More detail.....

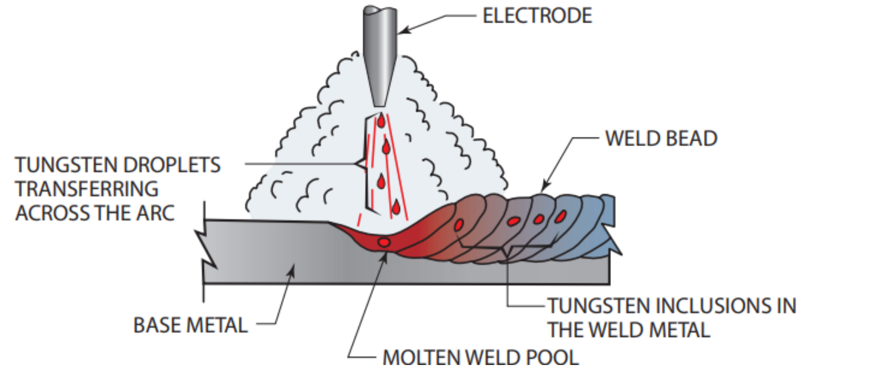
Electrode surface quality

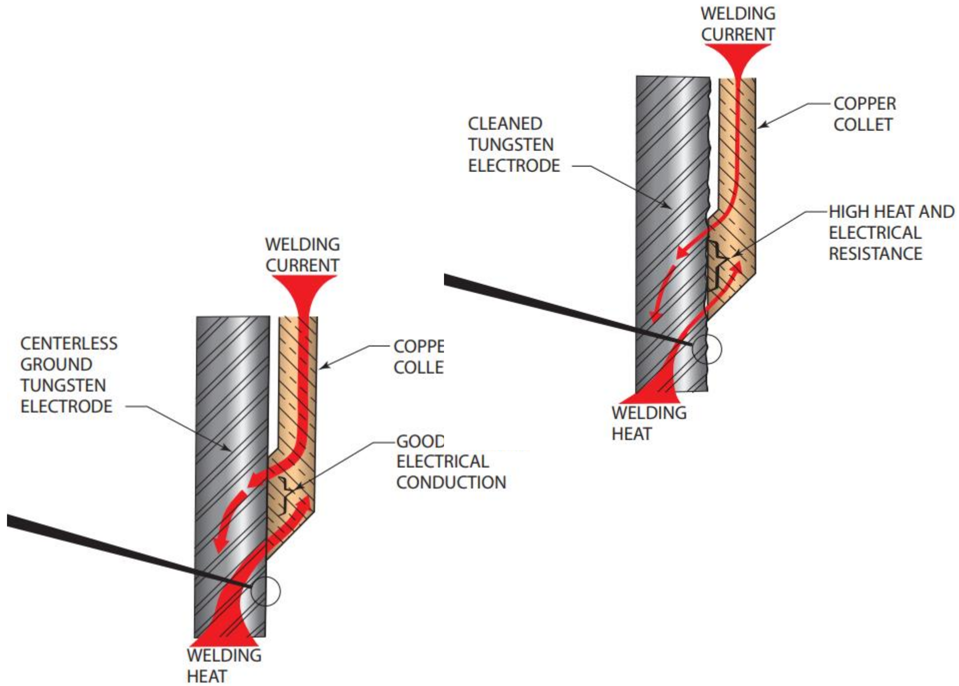
Surface quality of electrode is important to create as low a resistance between the electrode and workpiece as possible.

Increased resistance increases electrode temperature accelerating erosion thus reducing electrode lifespan and increasing tungsten inclusions in the weld.

When produced a tungsten electrode will have a heavy black oxide layer that needs to be removed.

Manual removal can lead to a rough surface so electrodes are usually ground to produce a smooth surface finish.





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TIG electrode

- Electrode is a tungsten rod
- Non consumable electrode (does not provide the filler material)
- Electrodes do need to be replaced

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TIG electrode materials

In addition to pure Tungsten compositions with 0.7 – 4.0% addition of oxides of ;

- Thorium
- Lanthanum
- Zirconium
- cerium
- Rare Earth Elements

International colour classification system

Region	Standard
US	ANSI/AWS A5.12
Canada	ASME /SFA
Europe	ISO 6848
Japan	JIS

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Pure tungsten (Green) – 99.5% tungsten minimum.

- Low cost.
- Provide good arc stability.
- Typically used with a ball ended electrode for AC welding.

Ceriated (Grey) – 2% Cerium Oxide (Ceria)

- Addition increases electron emission, improving striking and current capacity.
- Improved arc stability, but will degrade at high current/temperatures.
- Typically used with a pointed electrode.

Lanthanated (Black, Gold, Blue) – 1, 1.5, 2% lanthanum oxide (Lanthana).

- Addition improves arc striking, erosion rate and arc stability.
- Differing levels provide up to 50% additional current capacity. It also changes the arc voltages.
- Suitable for pointed or ball ended electrode types.

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Thoriated (Yellow, Red) – 1, 2% thorium dioxide (Thoria)

- Addition improves arc performance and also the electrode life.
- Thorium electrodes form small spikes rather than balling. This renders them unsuitable for AC as the arc will jump between them. They are suitable for DC
- Thorium is radioactive increasing health hazards from vapour and grinding dust.

Zirconiated (White) – 1% zirconium.

- Addition produces a very stable arc and greatly reduced tungsten spitting, reducing weld contamination.
- Used for AC welding applications with a ball finished end.

It is important to remember to grind the non painted end of the electrode when preparing the electrode for use.

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TIG Tungsten Types

Name	ISO 6848 Classification	Principal Oxide	Oxide Mass Percent	TIG Mode	Color
Pure Tungsten	EWP/WP	None	N.A.	AC	Green
Thoriated	EWTh-1/WT10	ThO_2	0.8 - 1.2%	DC	Yellow
	EWTh-2/WT20	ThO_2	1.7 - 2.2%	DC	Red
Ceriated	EWCe-2/WCe20	CeO_2	1.8 - 2.2%	DC or AC/DC	Grey
Lanthanated	EWLa-1/WLa 10	$La2O_3$	0.8 - 1.2%	DC or AC/DC	Black
	EWLa-1.5/WLa 15	$La2O_3$	1.3 - 1.7%	DC or AC/DC	Gold
	EWLa-2/WLa 20	$La2O_3$	1.8 - 2.2%	DC or AC/DC	Blue
Zirconiated	EWZr-1/WZr 3	ZrO_2	0.15 - 0.5%	AC	Brown
	EWZr-8 WZr 8	ZrO_2	0.7 - 0.9%	AC	White
Rare Earth Mix	EWG	Manufacturer identifies all additives	Manufacturer states quantities	DC or AC/DC	Manufacturers can select colors not used by welding codes

Chart from Weldguru.com

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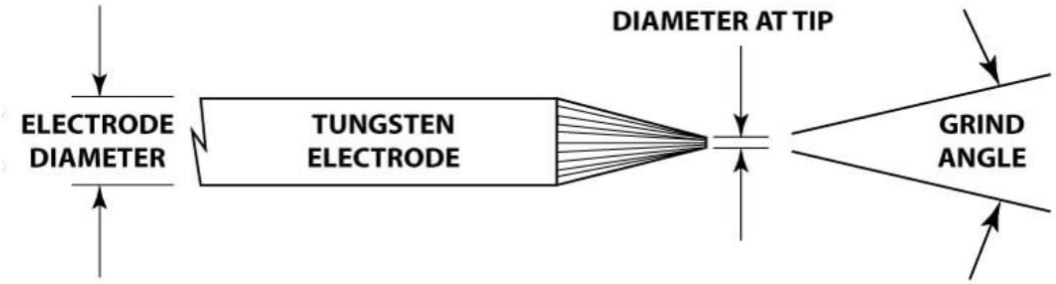
TIG TIP Geometry

- Electrode tip needs to be ground to form a conical shape
- Eases arc ignition and creates a more focused arc
- Select appropriate tip angle and geometry (Pointed, truncated or ball)



https://workshopinsider.com/tungsten-electrode-sharpening/

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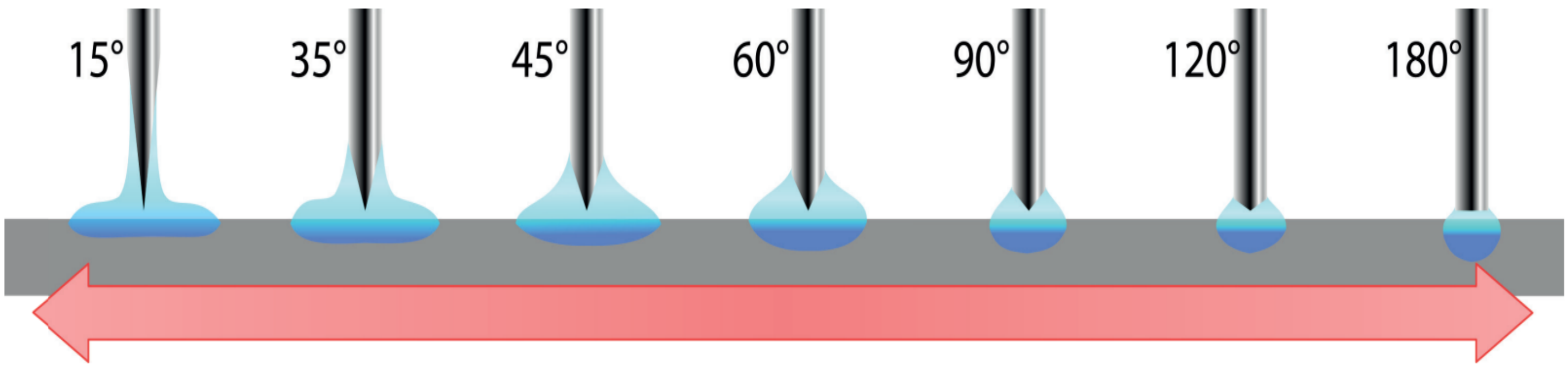

SHARP TIP

- Improves the stability of yours arc
- While welding with Less amps
- Less weld penetration
- Shorter electrode life
- Wider weld bead
- Easier arc starting

BLUNT TIP

- Higher chance of the arc wandering
- While welding with more amps
- Better weld penetration
- Longer electrode life
- Narrower weld bead
- Harder arc starting

https://www.gcegroup.com/files/technical-datasheets/INDUSTRIAL/accessories/Preparing_the_Electrode_Tip_EN.pdf

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Pointed/Truncated TIP


Pointed tip


Truncated tip

- Pure tungsten, ceriated, lanthanated, and thoriated
- Inverter AC and DC current
- Pointed tip -Reduces distortion for thin (0.1 to 1.0 mm) materials at low current
- Truncated tip - Prevents high current from melting tip

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Ball ended

- Normally pure tungsten and zirconiated electrodes
- AC process (sine wave) and conventional square wave
- To ball the end simply grind a point and apply the recommended AC current
- Ball should not exceed 1.5x electrode diameter
- Ball ended electrodes can reduce arc stability and can fall off and contaminate the weld

Source from: https://workshopinsider.com/tungsten-electrode-sharpening/

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Electrode shaping

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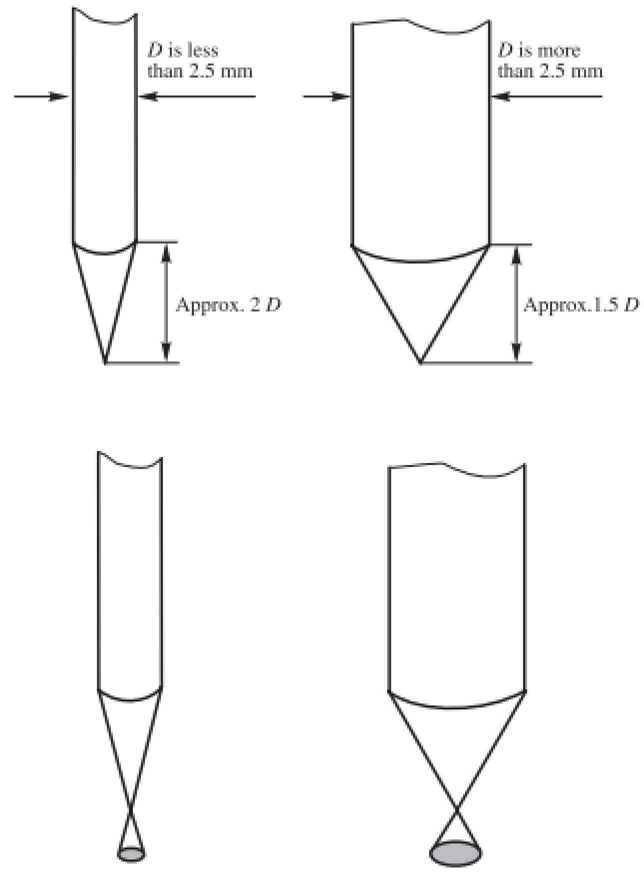
Tungsten electrodes should have the following characteristics.

- Blunting the point by around 0.5mm increases the lifetime of the electrode by removing the small concentrated area that would heat up quickly.
- Rounded electrodes should be smoothed off and consistent as possible and not larger than the diameter of the electrode
- If you are working with thin material, a pointed tip is useful to prevent workpiece distortion.
- At high currents the tip should be truncated or there is a risk of the tip blowing off into the weld.

In the case of a contaminated tip, non lanthanated tungsten is brittle and should break with pliers into a roughly flat shape that can then be ground to shape. The tip should be retained and recycled.



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Electrode shaping

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It is necessary to shape an electrode in 2 situations.

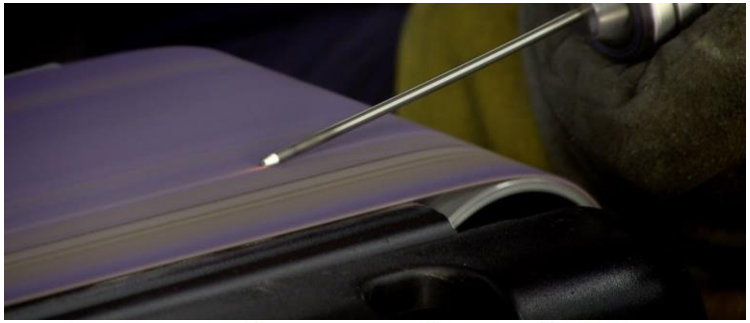
- When you initially prepare an electrode for use.
- If the electrode tip has become contaminated or damaged.

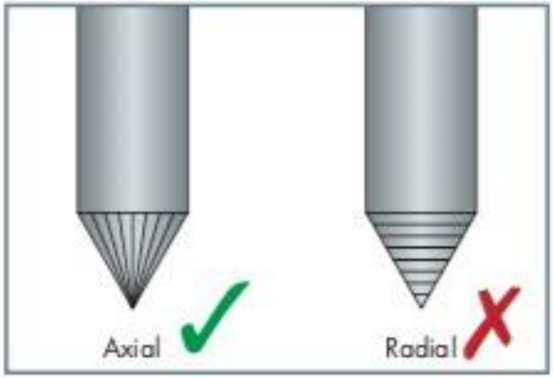
As mentioned earlier you grind tungsten to shape it using a grinding wheel.

- Grinding should be axial (B) to the point rather than radial (A). This reduces the amount of small particles of tungsten that can contaminate the weld.
- Griding should use a fixture (B) rather than be held by hand (A). This enables the required accuracy and protects your hand from harm.

A

B





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[Tungsten Grind Angles Matter! - YouTube]

Insert this video when on site.

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Electrode size

It is important to choose the right diameter of base electrode for your application. This is decided by your current and welding technology.

RECOMMENDED AMPERAGE (according to ISO 6848: 2015)

Electrode Diameter (mm)	Direct Current (DC)			Alternative		
	Electrode negative (-)	Electrode positive (-)		Arc Balance 50% electrode (+) 50% electrode (-)		Arc Balance 30% electrode (+) 70% electrode (-)
	Tungsten with oxide additives	Tungsten with oxide additives	Pure Tungsten	Pure Tungsten	Tungsten with oxide additives	Tungsten with oxide additives
1,0 mm	10-75 A	not applicable	not applicable	25-60 A	25-75 A	25-80 A
1,6 mm	45-150 A	10-20 A	10-20 A	50-100 A	40-110 A	40-125 A
2,0 mm	60-200 A	15-25 A	15-25 A	60-130 A	60-130 A	60-150 A
2,4 mm	75-220 A	15-30 A	15-30 A	70-130 A	65-150 A	60-175 A
3,2 mm	85-330 A	20-35 A	20-35 A	90-150 A	75-170 A	75-250 A
4,0 mm	100-400 A	35-50 A	35-50 A	95-170 A	85-210 A	85-310 A
4,8 mm	120-480 A	50-70 A	50-70 A	100-240 A	90-300 A	95-340 A

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[4 Easy Ways to Grind Tungsten for TIG Welding | TIG Time - YouTube]

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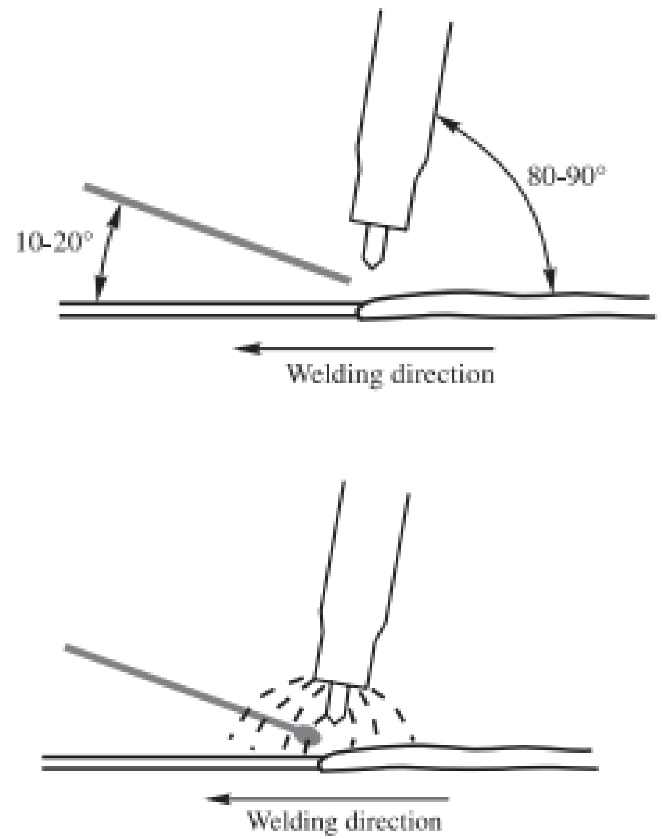
Filler technique

In terms of filler technique the following are important to consider.

- Keep the torch at around an 80-90° angle and the filler at a 10-20° angle.
- Feed the filler in progressively, tap it into the edge of the weld pool to add to it.
- Ensure the wire remains within the gas flow to prevent oxidation.
- Do not allow the filler or weld pool to touch the electrode.
- Ensure that your filler, torch and workpiece are all clean before beginning.

The precise filler material you use will be dependent on the material and the type of join you want to achieve so specific alloys will not be covered here.



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Filler technique

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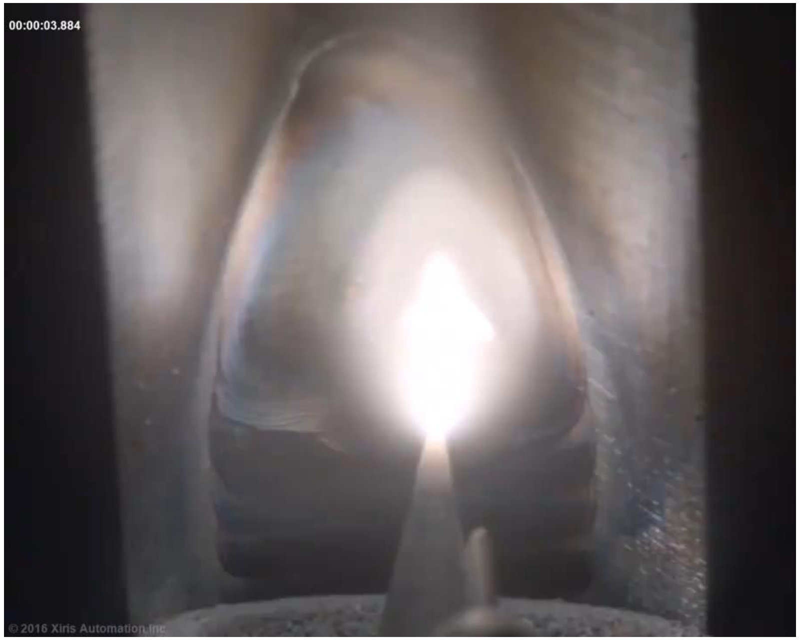
There is no one way to feed in all circumstances, however this video shows a good general approach, there are many video sources for better welding technique available and ones specific to particular applications.

[TIG Welding Technique: The Dab Method Tips and Tricks | TIG Time - YouTube]

TiP - TIG

TiP-TIG is a subset of TIG welding that differs from traditional TIG by manipulating the filler wire.

- Mechanical agitation of the filler wire causes vibrations in the melt pool. This increases fluidity and breaks the surface tension allowing inclusions to escape more easily improving weld quality.
- Pre-heating of the filler wire reduces the need for heat input by the arc torch which in turn reduces the HAZ of the weld.



The weld pool is more able to accept a greater deposition rate of filler which increases potential weld speed. It also provides a more uniform weld pool as it solidifies due to the stirring effect of the oscillations, along with a lower heat input reducing stress.

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Applications of TIG welding

TIG (or GTAW) welding was developed in the late 1930's to address the needs of the aircraft industry to weld materials such as Magnesium and Aluminium.

It had two clear advantages that made it suitable for these challenging materials:

- Use of shielding gas prevents oxide formation at elevated welding temperatures.
- Non consumable electrode gives very consistent energy input independent of material feed speed (leading to a controllable high quality weld) and the ability to use for pre/post heating

TIG is used in areas where weld quality is prioritised over productivity, or when a material is difficult or impossible to weld with other processes (process is slower than MIG)

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Applications of TIG welding

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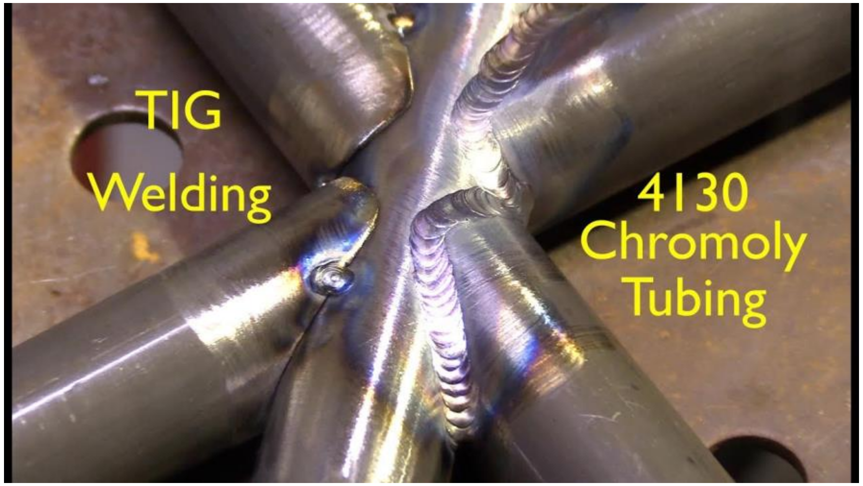
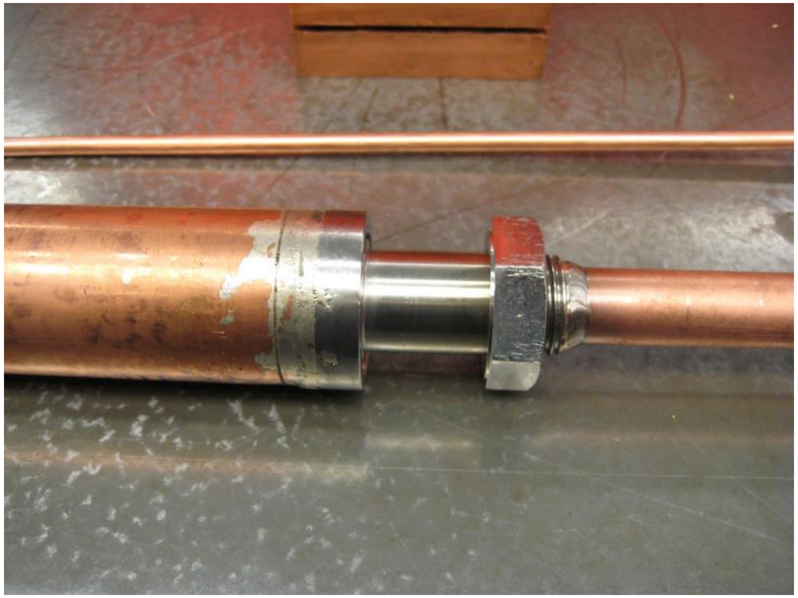
Materials that would typically be TIG welded:

- Stainless steel
- Chromoly steel
- Titanium
- Aluminium
- Nickel alloys
- Magnesium

TIG can be applied most metals - it may not be the best choice for other materials not listed here, but it will very likely be able to do it.

Another is that it is excellent for welding dissimilar materials due to its flexibility as shown in the copper-stainless steel joint





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Applications of TIG welding

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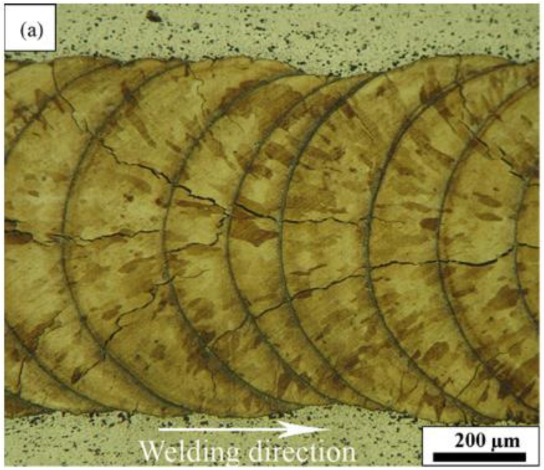
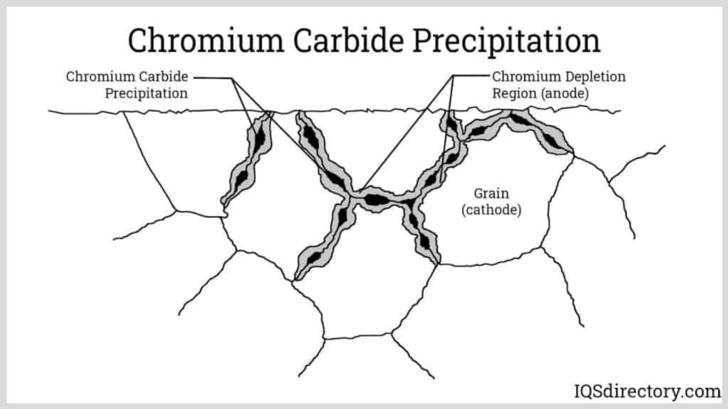
Applications where Internal weld quality is critical…

- TIG offers greater control over heat input which helps reduce cracking in metals like Aluminium with high thermal shrinkages which is critical for aerospace, or in thin parts in other materials where heat control is critical.

- Use of shielding gas for austenitic steels where alloying elements react with the atmosphere and precipitate along grain boundaries. This is particularly critical in nuclear applications for tubing which has both high strain on the welds and also a very high impact of failure.





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Applications of TIG welding

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Applications where external weld quality is critical….

- TIG has lower filler requirements and because of its consistency produces an attractive consistent weld. This is frequently used in bicycle production for the welding of thin section aluminium, steel or titanium tubes.

- Food & beverage applications, its critical that all welds be smooth so that they provide no crevasses for bacteria to grow and it can be well sterilised.

- TIG should not produce spatter or effects outside the weld area and doesn’t require flux which improves the weld aesthetics.

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Material preparation

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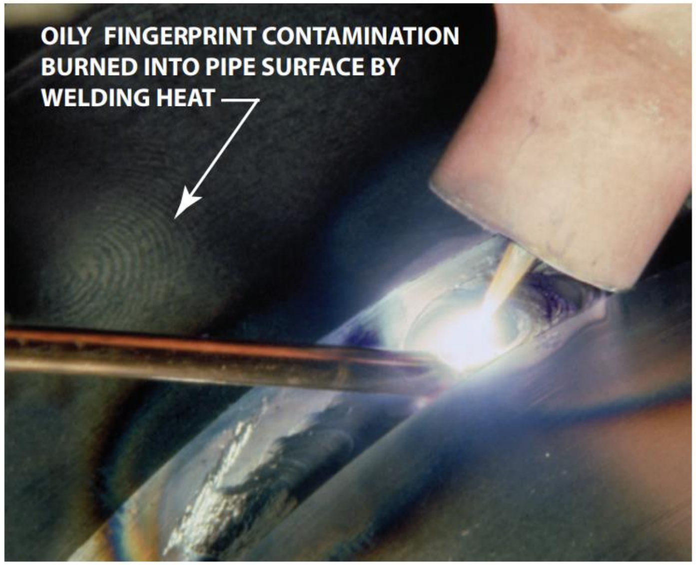
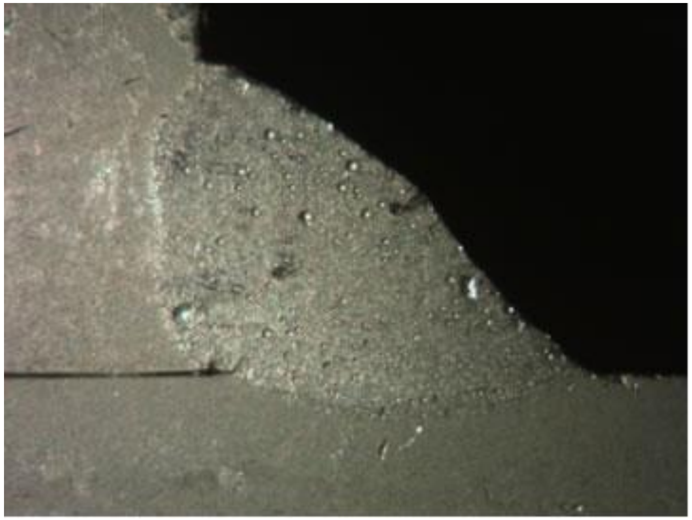
Material preparation is critical in TIG welding…..

- Joint areas should be cleaned of all oil or grease before processing, especially in sensitive materials with the use of acetone or alcohol.
- Highly oxidisable materials such as aluminium should have oxide mechanically removed using a stainless steel brush to prevent contamination.
- Contamination leads to porosity and inclusions in welds, reactive gases like oxygen, nitrogen or hydrogen absorb into the melt pool then as solubility drops during solidification are entrapped as gas bubbles in the solidified melt.





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Defects - Discolouration

TIG welding is one of the most difficult welding processes to master and so a variety of defects can occur.

Welds can discolour in a variety of ways, they can be sooty or blackened or a different colour to the base metal depending on the metals composition.

In stainless steel a coloured weld indicates oxidation has taken place, this can lead to reduced corrosion resistance properties. Titanium will also have a similar issue, but it is more likely to indicate significant problems with the weld.

Causes of weld discolouration are typically one of the following: Poor shielding gas coverage, unclean work surface, weld technique (filler rod angle, speed, distance of electrode to workpiece).

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Defects - Porosity

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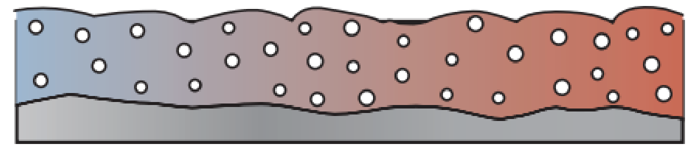
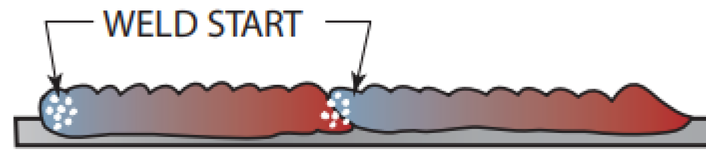
Weld porosity takes 4 general forms.

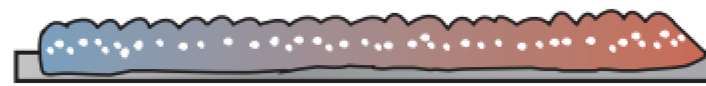
- **Uniform distributed porosity** - tends to be due to poor technique or materials quality.
- **Clustered porosity** - tends to be caused by poor starting and stopping techniques.
- **Linear porosity** - usually caused by surface contamination or boundaries between welds.
- **Piping porosity** - nonspherical elongated pores and usually has a direction parallel to the welds solidification direction. Caused by gas escaping at a similar rate to the weld solidifying leaving a “tail”.



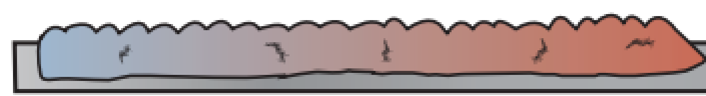
SECTION A-A



SECTION A-A



SECTION A-A



SECTION A-A

Porosity is caused by absorption of gas into molten weld pool, which is released as weld solidifies and becoming entrapped as pores. Gas can originate from the atmosphere or surface contamination of grease or oxides, types include oxygen, nitrogen or hydrogen.
Good workpiece cleaning and shielding gas usage will address porosity issues.

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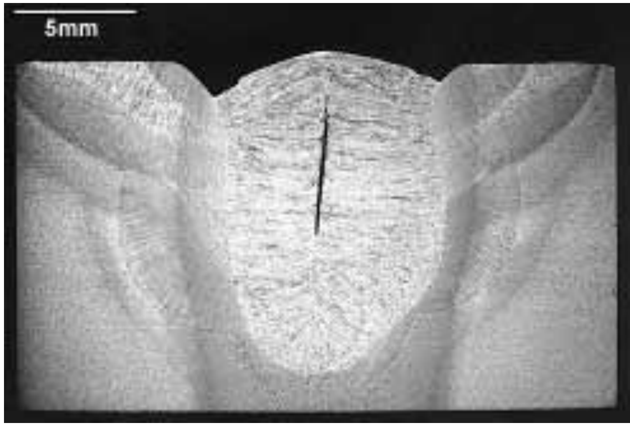
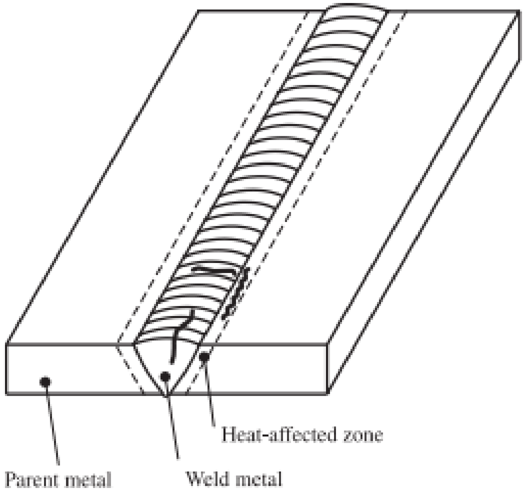
Defects - Cracking

Cracking is caused by thermal shrinkage, this introduces high quantities of stress because as the weld cools it contracts. The material may then fracture in a variety of ways to relieve that stress.



- Cracks within or at edge of weld usually caused by high cooling rates exacerbating existing problems with material (Such as aluminium's high thermal shrinkage) or insufficient liquid melt to fill the gap. These are best addressed by controlling solidification rate with heat or weld speed and if necessary good selection of filler material.
- Delaminating cracks, the stress introduced by welding can cause areas disconnected from the main area to separate, such as laminated areas or other welds disconnected from the main area.



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Defects – other

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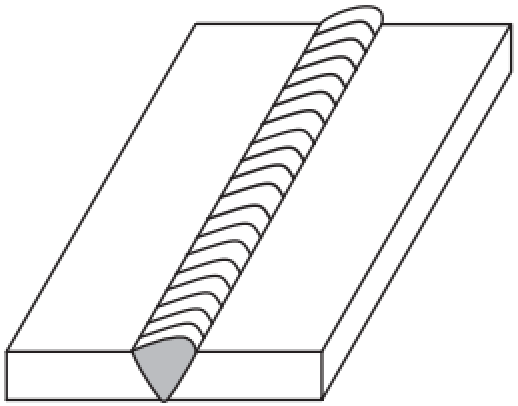
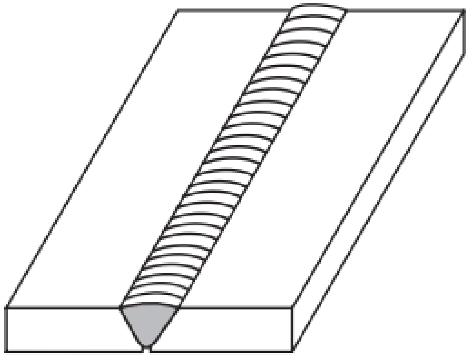
There are a few other types of defects that can occur in TIG welding.

- **Excess or insufficient weld material** - leads to either overlapping where weld pool swells out but doesn't bond properly to the material, underfill is the opposite problem. Both are generally solved by altering the speed of welding.
- **Arc strikes-** arc jumps off the weld pool and strikes the surface of the material scorching it and can form a discontinuity of a much harder area or an area where cracks may initiate.
- **Lack of fusion** - can take a variety of forms but are usually related to either a lack of heat input, poor joint design or surface contamination. This is addressed by welding technique.
- **Excess Heat Affected Zone** - heat build-up from poor energy input control can lead to an enlarged HAZ which is a structurally compromised area of the part.



Excess weld material defect



Incomplete root penetration defect

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Usage in industry

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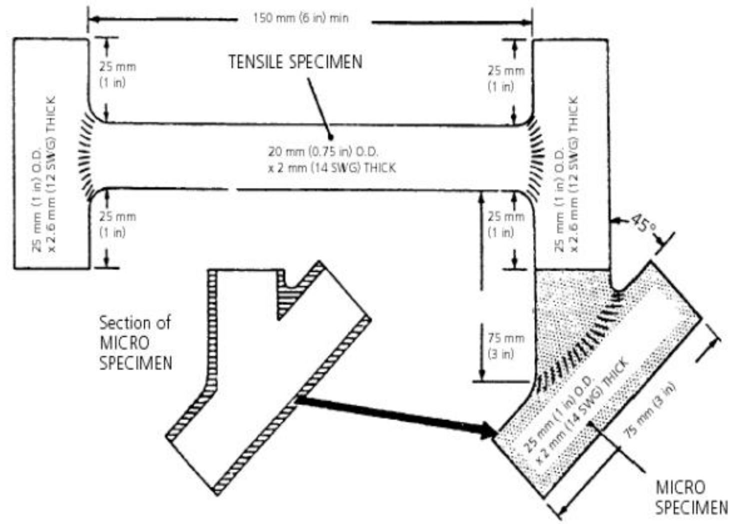
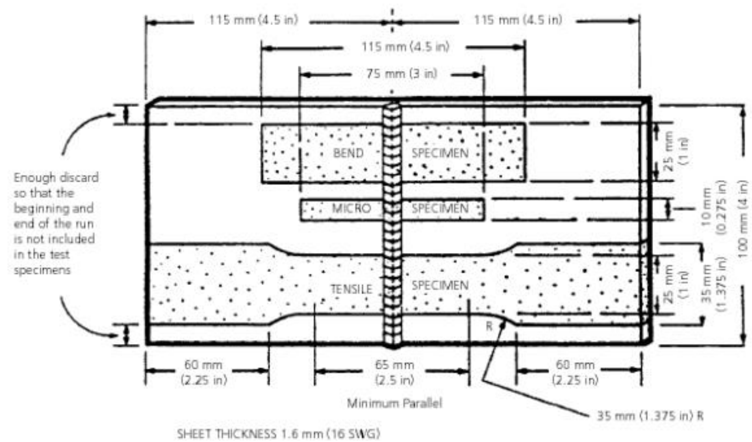
TIG welding is used very frequently in aerospace, it is highly regulated for safety reasons. Welders need to pass various competency tests to be approved to work on airframes, 3 major relevant standards are as follows:

- Civil Aviation Authority – BCAR A8-10 UK relevant qualification standard for airworthiness.
- ISO 17927 – ISO standard for fusion welding of metallic components for aerospace.
- NADCAP AC 7110– National Aerospace and Defence Contractors Accreditation Program. This is used by all major aircraft manufacturers.

The qualification standards require competent welders to make the welds which are free of defects and to maintain that standard through certification to work on aerospace applications





Usage in industry

[Bicycle Frame Build 35 - Tig Weld Bicycle Main Triangle - YouTube]

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Advantages and disadvantages

The majority of these advantages and disadvantages have been covered in detail elsewhere in the presentation so this serves as a summary slide.

Advantages	Disadvantages
Can weld almost any material, especially challenging ones.	Requires a high degree of operator skill and practice to execute
Can produce very high quality weld due to excellent control of heat input.	Has a low throughput rate.
Produces welds free of contamination due to non consumable electrode and shielding gas and no spatter.	Requires high cost inert gases to operate.
No requirement for filler metal.	High UV levels result in significant danger to the welding operator without proper PPE

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Finally ….reminder about health & safety

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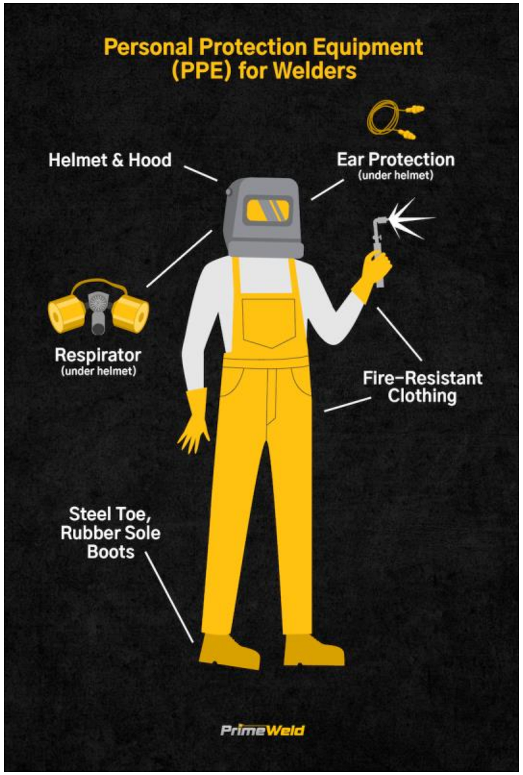
RECAP

Eye protection

- TIG welding presents significant danger to eyes from electromagnetic radiation
- Failure to use proper protection will lead to “arc eye” and can be dangerous at distances over 10m from the workpiece.
- Welding areas must avoid casual traffic and the area should be shielded off with a curtain or wall



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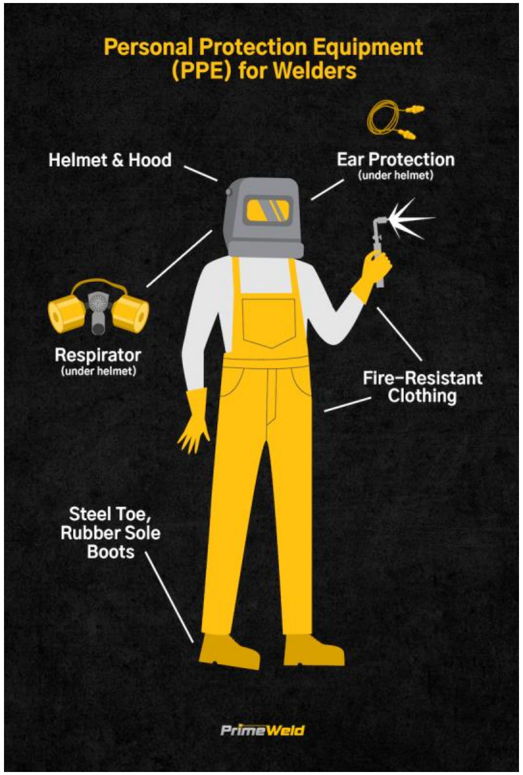
Skin protection

Heat and light also presents other hazards to the skin

- All skin should be covered up by long overalls
- TIG should typically use class 2 clothing.
- Gloves should be worn and cover well above the wrist to protect from sparks or weld pool splash.



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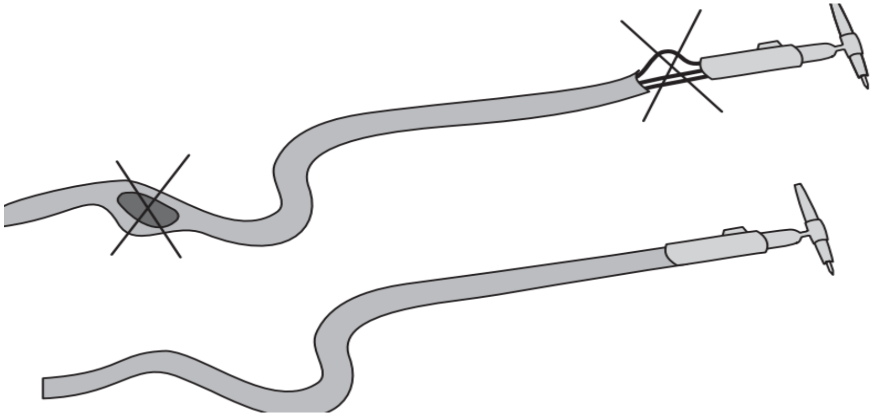
Health & Safety- Electrical Safety

Usually low risk, provided reasonable precautions taken;

- **Insulation of the main supply -** need to be checked for damage.
- **Earth Protection** - checked periodically (Potable Appliance Test - PAT)
- **Power source -** high frequency AC units have increased electric risk and should only be operating in a dry environment



Source: PerfectWelders.com

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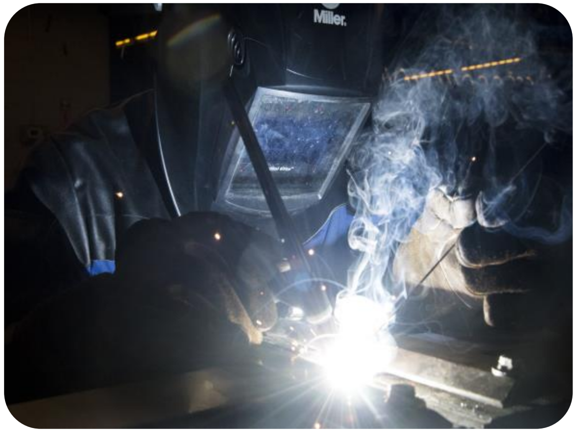
Health & Safety Tig Welding- Welding Fumes

Although a flux free process TIG still presents a health risk from fumes;



Iron Oxide - welding of steel produces fumes with high levels of iron oxide which may cause reduced pulmonary function if inhaled

Nitrous Gases - nitrous gases are produced during welding . Some nitrous gases have a fixed TLV (Threshold Limit Value);

- TLV of nitrogen oxide (NO) is 25 PPM.
- TLV of nitrogen dioxide (NO_2) is 3 PPM.

If nitrogen oxide and ozone is mixed (as with TIG welding) nitrogen pentoxide is produced which is more toxic than other nitrous gases.

Inhalation of nitrous gases may only lead to minor irritation but exposure beyond TLV may cause instant and highly dangerous lung damage (e.g. pulmonary oedema and the pulmonary disease emphysema)

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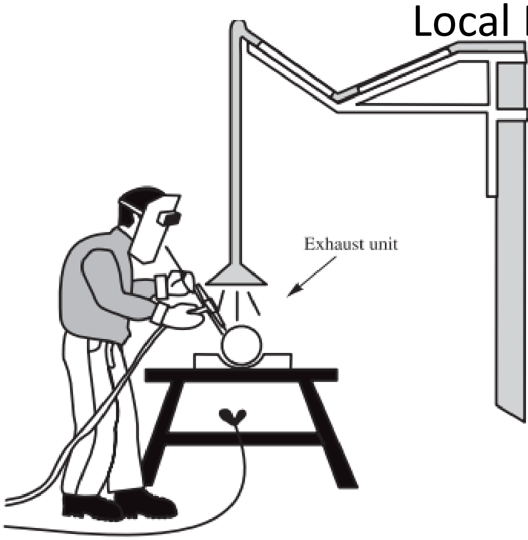
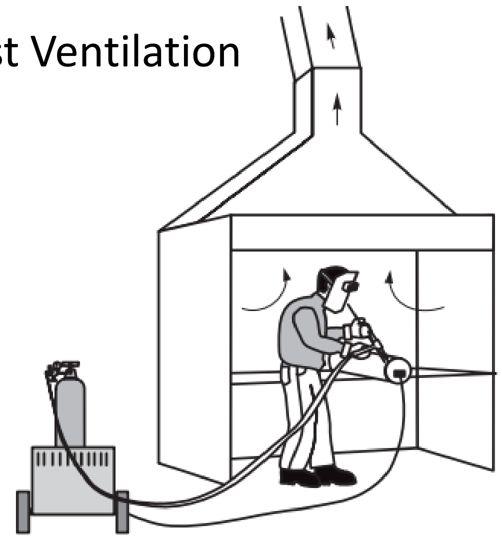
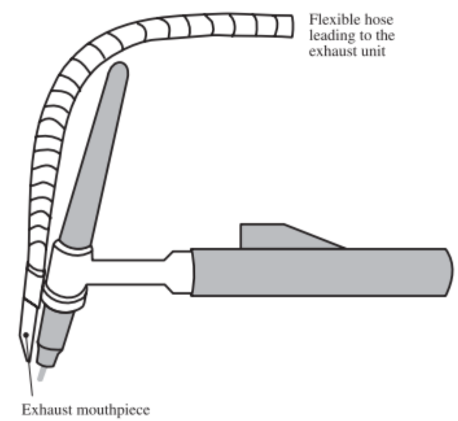
Health & Safety -Local Exhaust Ventilation

Suitably specified local exhaust ventilation (LEV) should be used to remove welding fumes from the welding area

Local Exhaust Ventilation







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Thank you & Questions ?

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