Fusion Welding

1. Energy source

Classification of Fusion welding based on energy source

Energy source	Types of welding
Chemical	Oxy fuel gas welding, Exothermic welding/ Thermite welding, Reaction brazing/Liquid phase bonding
Radiant energy	Laser beam welding, Electron beam, Infrared welding/ brazing, Imaging arc welding, Microwave welding,
Electric-Perm. electrode arc	Gas tungsten arc welding, plasma arc welding, Carbon arc welding, atomic hydrogen welding, Stud arc welding
Electric-Consumable electrode	Gas metal arc welding, Shielded metal arc welding, Submerged arc welding, Electrogas welding, Electroslag welding, Flux cored arc welding
Electric-Resistance	Resistance spot, resistance seam, projection welding, flash/ upset welding, Percussion, Induction welding

The thermal class of welding includes all types of welding using thermal energy. Depending on various methods, the nature of the energy sources and alloys of the weldment welding can be divided into the following main types:

- gas welding;
- electric arc welding;
- electroslag welding;
- electron beam welding;
- plasma welding;
- laser welding;
- Thermite welding.

For the thermal class of welding is typical that the welding is carried out by melting the edges of the joined parts. So, a “bath” (welding pool, welding bead) of molten metal is formed. After the source of metal heating has been removed, the weld pool crystallizes and a weld seam, that connects the welded parts, is formed. Welding is a complex and fast physico-chemical process for materials joining. Preparation of blanks and well thought-out technology make fusion welding easy and fast.

OXYFUEL GAS WELDING

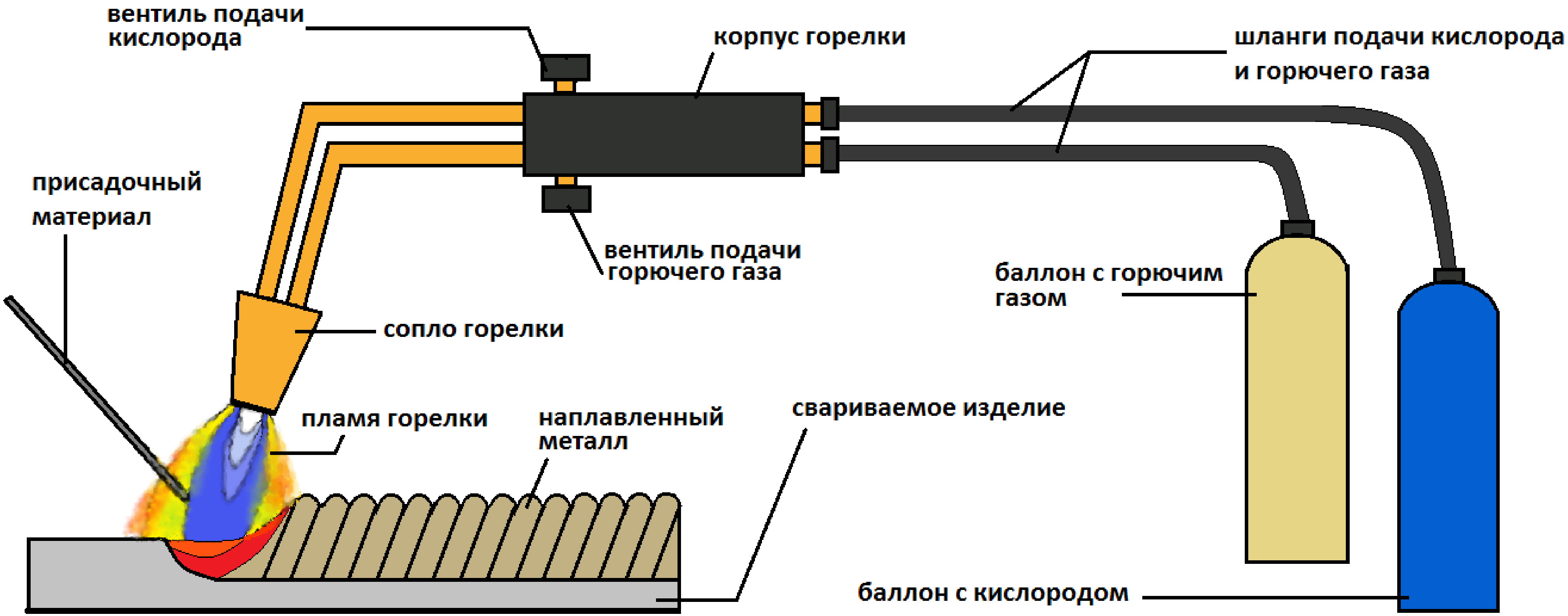
Class: Fusion Welding

Energy Source: Chemical type - High Temperature Flame

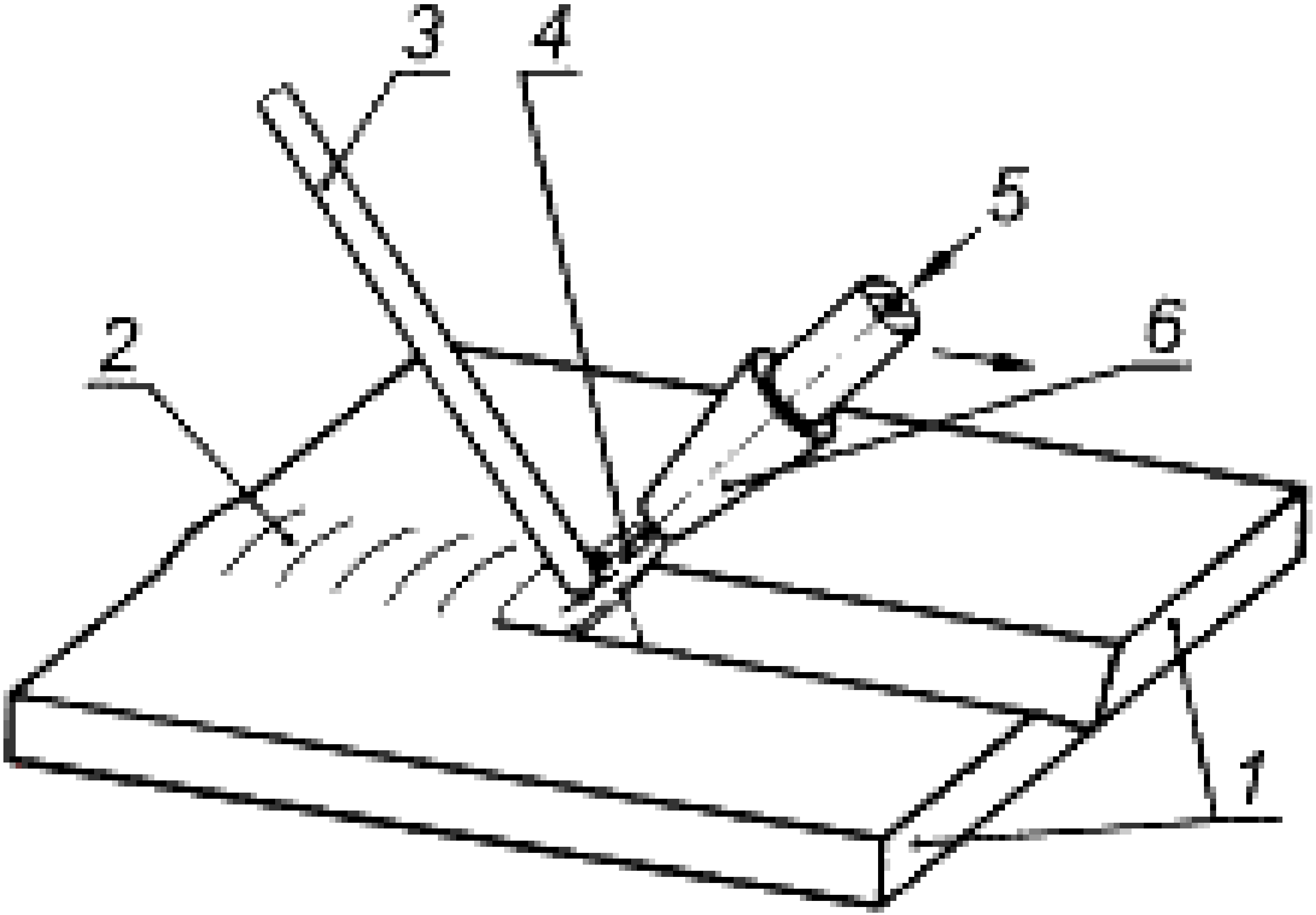
OXYFUEL GAS WELDING (OFW)

A group of welding processes producing coalescence of workpieces by heating them with an oxyfuel gas flame. The processes are used with or without the application of pressure and with or without filler metal. AWS A3.0M/A3.0:2010

Oxy Fuel welding (OFW) is a group of welding processes which join metals by heating them with a fuel gas flame or flares with or without the application of pressure and with or without the use of filler metal. OFW, Oxy Fuel welding includes any welding operation that makes use of a fuel gas combined with oxygen as a heating medium. The process involves the melting of the base metal and a filler metal, if used, by means of the flame produced at the tip of a welding torch. In OFW, Oxy Fuel welding Fuel gas and oxygen are mixed in the proper proportions in a mixing chamber which may be part of the welding tip assembly. Molten metal from the plate edges and filler metal, if used, intermix in a common molten pool. Upon cooling, they coalesce to form a weldment.

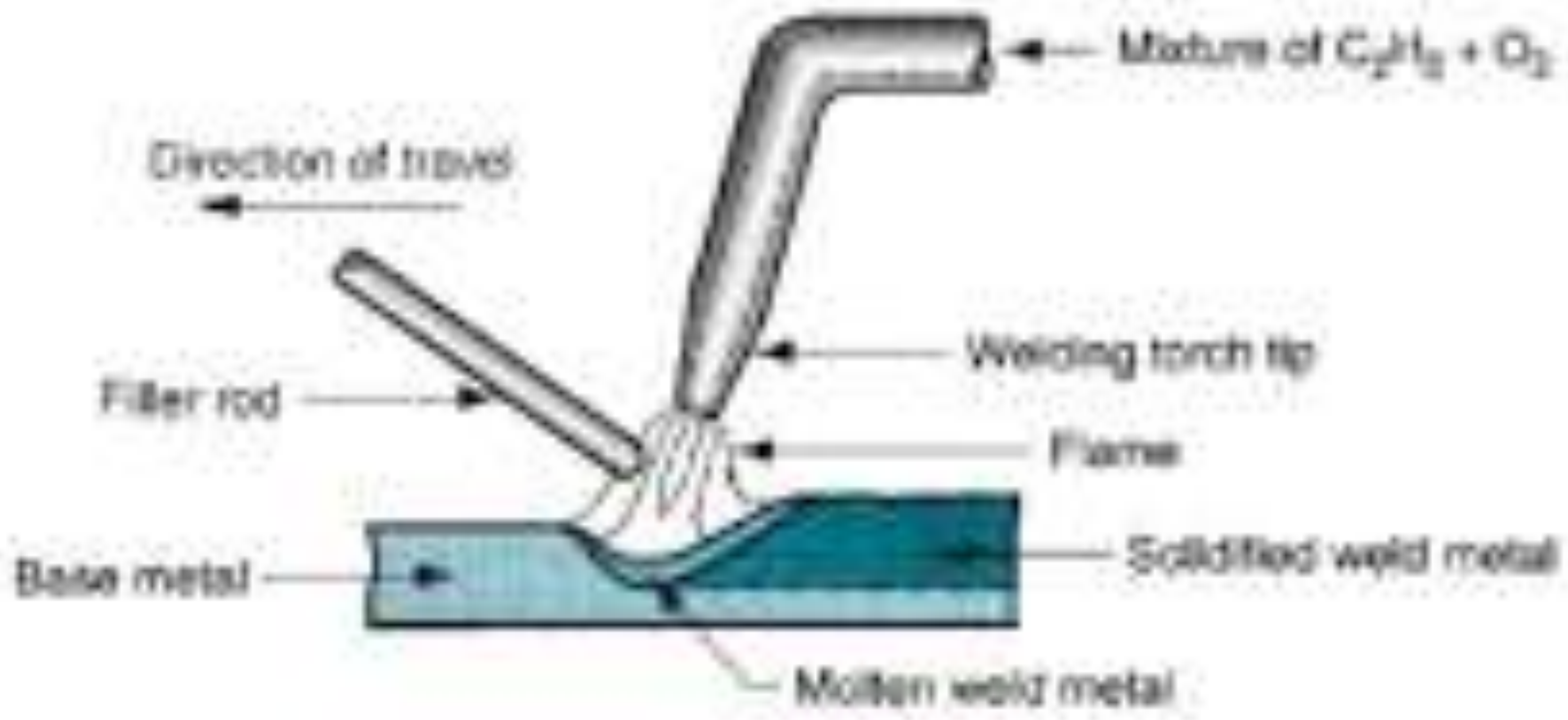


OXYFUEL GAS WELDING,
scheme of process

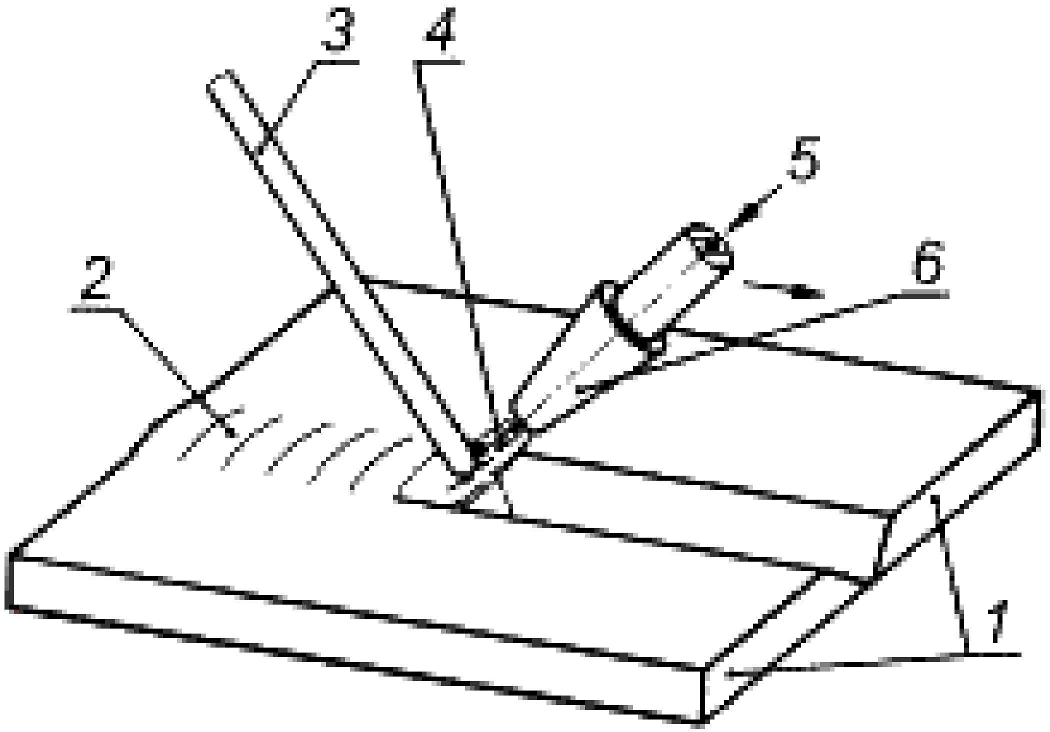


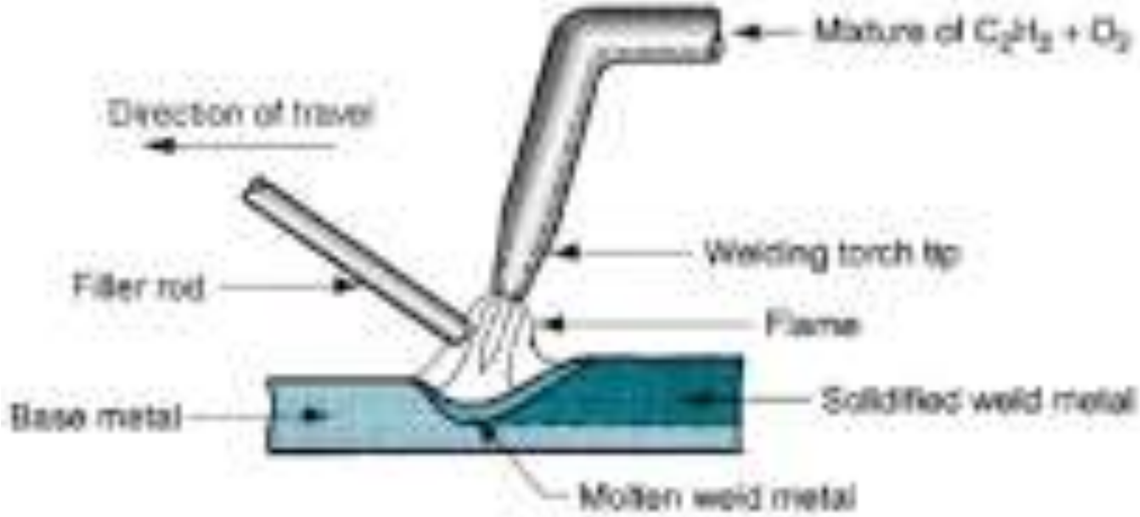
1-заготовка; 2-сварной шов; 3-присадочный металл; 4-газовое пламя; 5-горючий газ и кислород; 6-сварочная горелка

Oxy-acetylene welding (OAW) operation



Oxy-acetylene welding (OAW) operation





OXYACETYLENE WELDING (OAW)

An oxyfuel gas welding process employing acetylene as the fuel gas. The process is used without the application of pressure. See Figure B.40. AWS A3.0M/A3.0:2010

OXYHYDROGEN WELDING (OHW)

An oxyfuel gas welding process employing hydrogen as the fuel gas. The process is used without the application of pressure.

OXYPROPANE WELDING

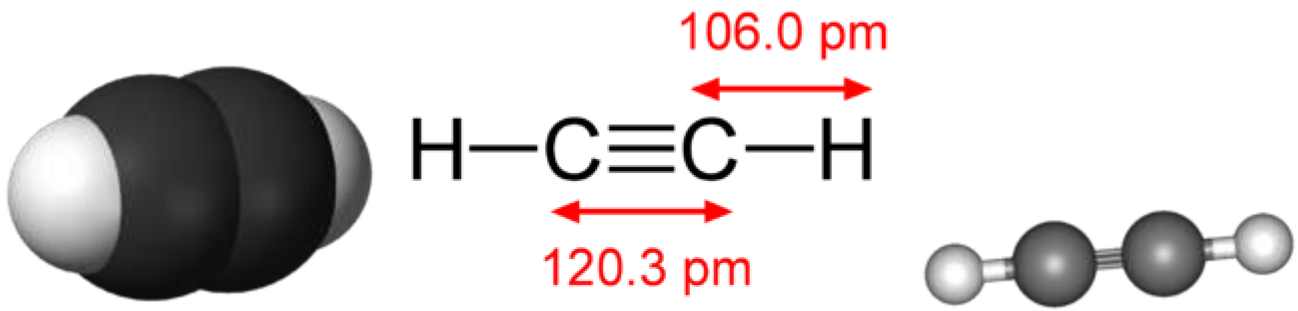
OXIDIZING FLAME

An oxyfuel gas flame in which there is an excess of oxygen, resulting in an oxygen-rich zone extending around and beyond the cone. See Figure B.40(C). See also carburizing flame, neutral flame, and reducing flame.

REDUCING FLAME

An oxyfuel gas flame with an excess of fuel gas. See Figure B.40(D). See also carburizing flame, neutral flame, oxidizing flame, and reducing atmosphere.

Химическая формула	H_2	CH_4	C_3H_8 и C_4H_{10}	C_2H_4	C_6H_{12}	C_6H_6	C_2H_2
Наименование	Водород	Метан	Пропан	Этилен	Бензин	Бензол	Ацетилен
Содержание водорода, вес %	100,0	25,0	18,0	14,5	14,5	7,8	7,8
Содержание углерода, вес %	0,0	75,0	82,0	85,5	85,5	92,2	92,2
Теплота сгорания, кал/м^3	2570	9600	21000	15000	—	—	14000
Максимальная температура в смеси с кислородом, °С	2350	2200	2300	2500	2600	2800	3300



Acetylene

Table: Fuel Gas Characteristics				
Fuel Gas	**Maximum Flame Temperature °C**	**Oxygen to fuel gas Ratio (vol)**	**Heat distribution kJ/m3**	
			Primary	Secondary
Acetylene	3,160	1.2:1	18,890	35,882
Propane	2,828	4.3:1	10,433	85,325
MAPP	2,976	3.3:1	15,445	56,431
Propylene	2,896	3.7:1	16,000	72,000
Hydrogen	2,856	0.42:1	-	-
Natural Gas	2,770	1.8:1	1,490	35,770

For further information contact arc@twi.co.uk

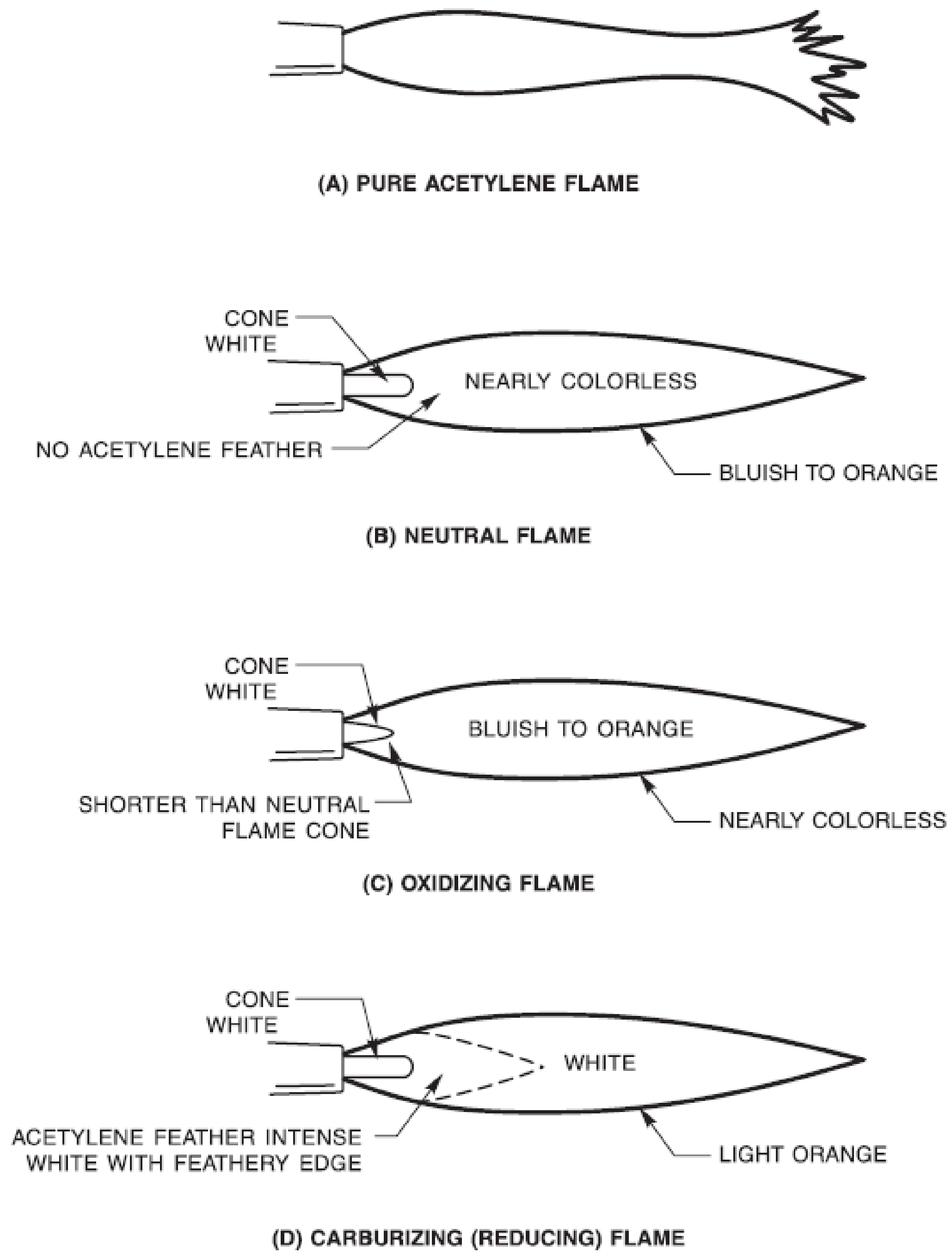


Figure B.40—Oxyacetylene Flame Types

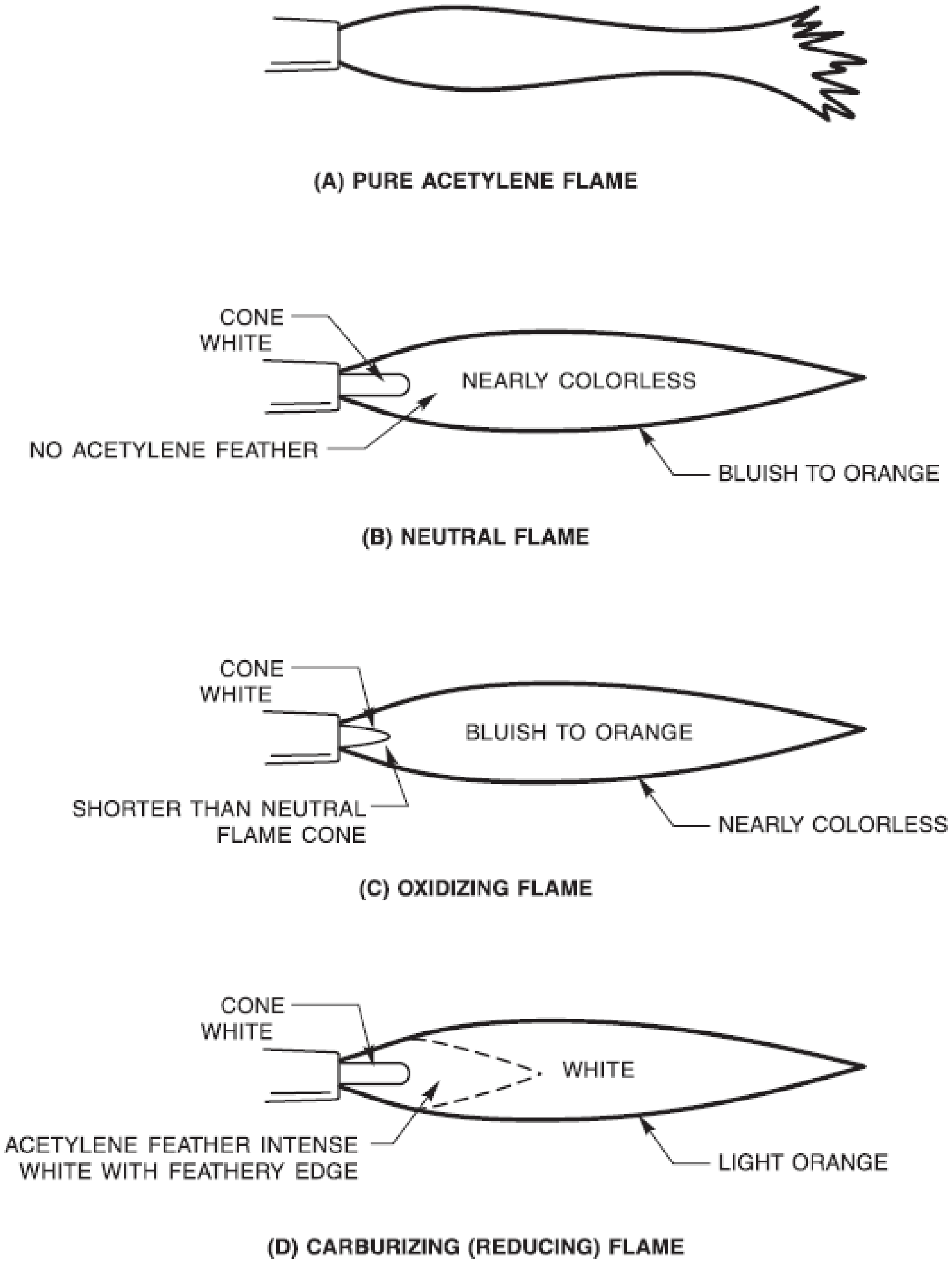


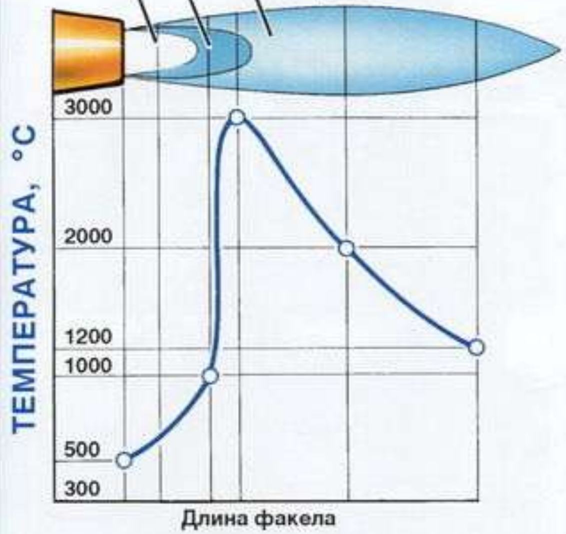
Figure B.40—Oxyacetylene Flame Types

СТРОЕНИЕ ПЛАМЕНИ

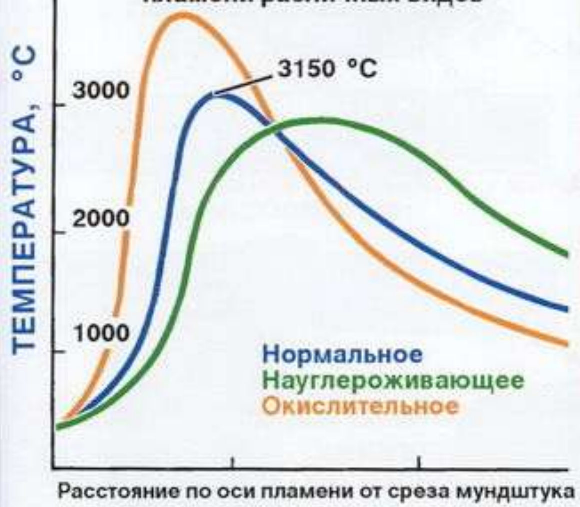
Ядро - продукты распада ацетилена, сгорающие в оболочке ядра

Восстановительная зона - окись углерода и водород, раскисляющие сварочную ванну

Факел - область полного сгорания



Изменение температуры пламени различных видов



ВИДЫ ПЛАМЕНИ

● НОРМАЛЬНОЕ

соотношение ацетилена и кислорода от 1:1 до 1:1,1

Ядро - резко очерченное, цилиндрической формы с плавным закруглением, ярко светящейся оболочкой, четко выражены все три зоны. Используют для сварки большинства сталей, сплавов и цветных металлов

● НАУГЛЕРОЖИВАЮЩЕЕ

соотношение ацетилена и кислорода более 1:0,95
(избыток ацетилена)

Ядро теряет резкость очертания, на конце появляется зеленый венчик, восстановительная зона бледнеет и почти сливается с ядром. Факел желтеет. Используют для сварки чугуна, наплавки твердыми сплавами

● ОКИСЛИТЕЛЬНОЕ

соотношение ацетилена и кислорода менее 1:1,3
(избыток кислорода)

Ядро конусообразное, укороченное, имеет менее резкие очертания, бледнеет. Пламя - синевато-фиолетовое, горит с шумом. Все зоны сокращаются по длине. Окисляет металл. Шов получается хрупким и пористым. Используют при сварке латуни

СОСТАВ ПЛАМЕНИ	Максимальная температура, °С	Расстояние, на котором достигается максимальная температура
Ацетилено-кислородное	3150	2-6 мм от конца ядра
Пропан-бутан-кислородное	2400	2,5 длины ядра от среза мундштука
Метан-кислородное	2150	3-3,5 длины ядра от среза мундштука

МОЩНОСТЬ ПЛАМЕНИ - характеризуется количеством ацетилена, проходящего за 1 час через горелку, необходимым для расплавления 1 мм толщины свариваемого металла. Регулируется наконечниками и вентилями горелки участкам поверхности металла.

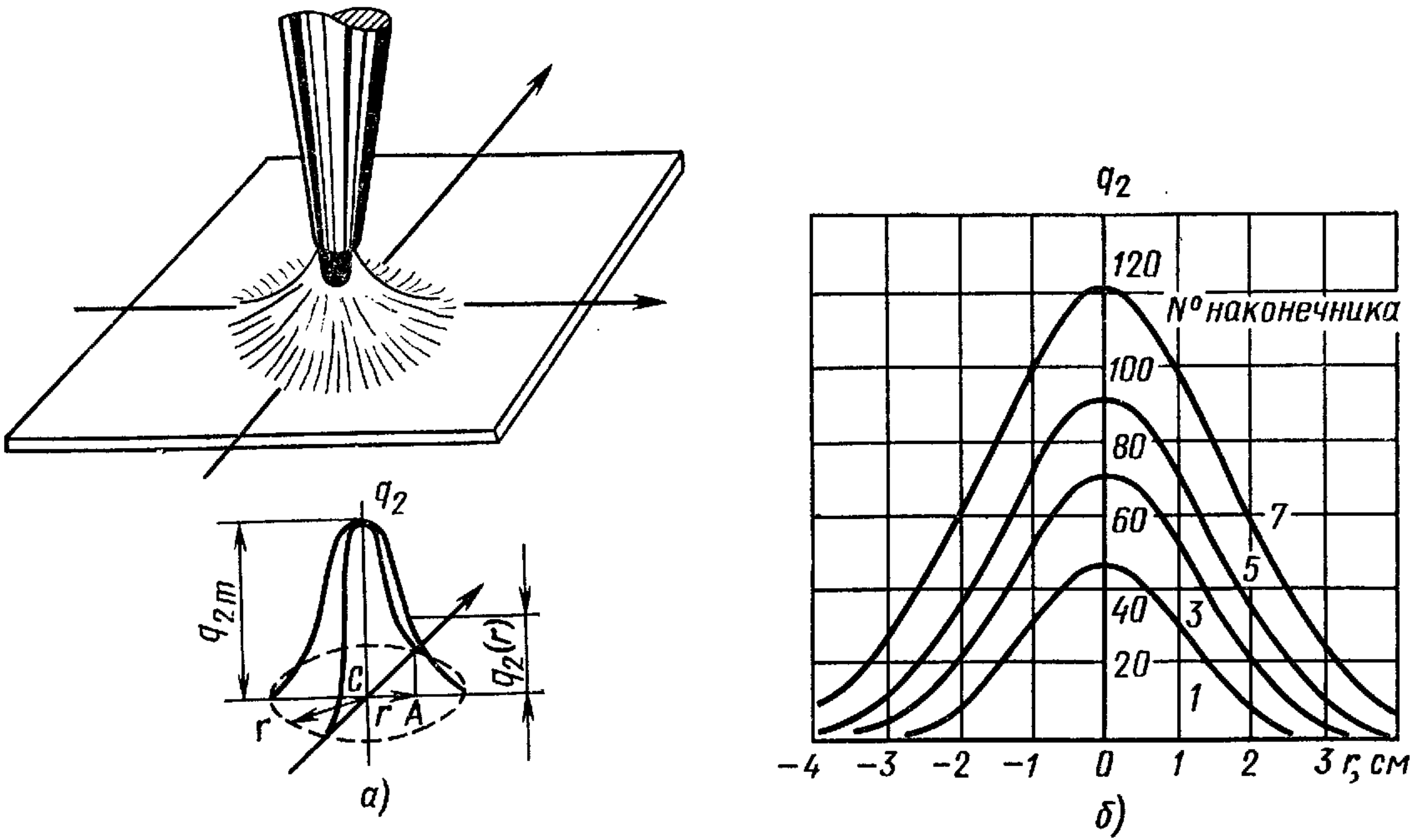
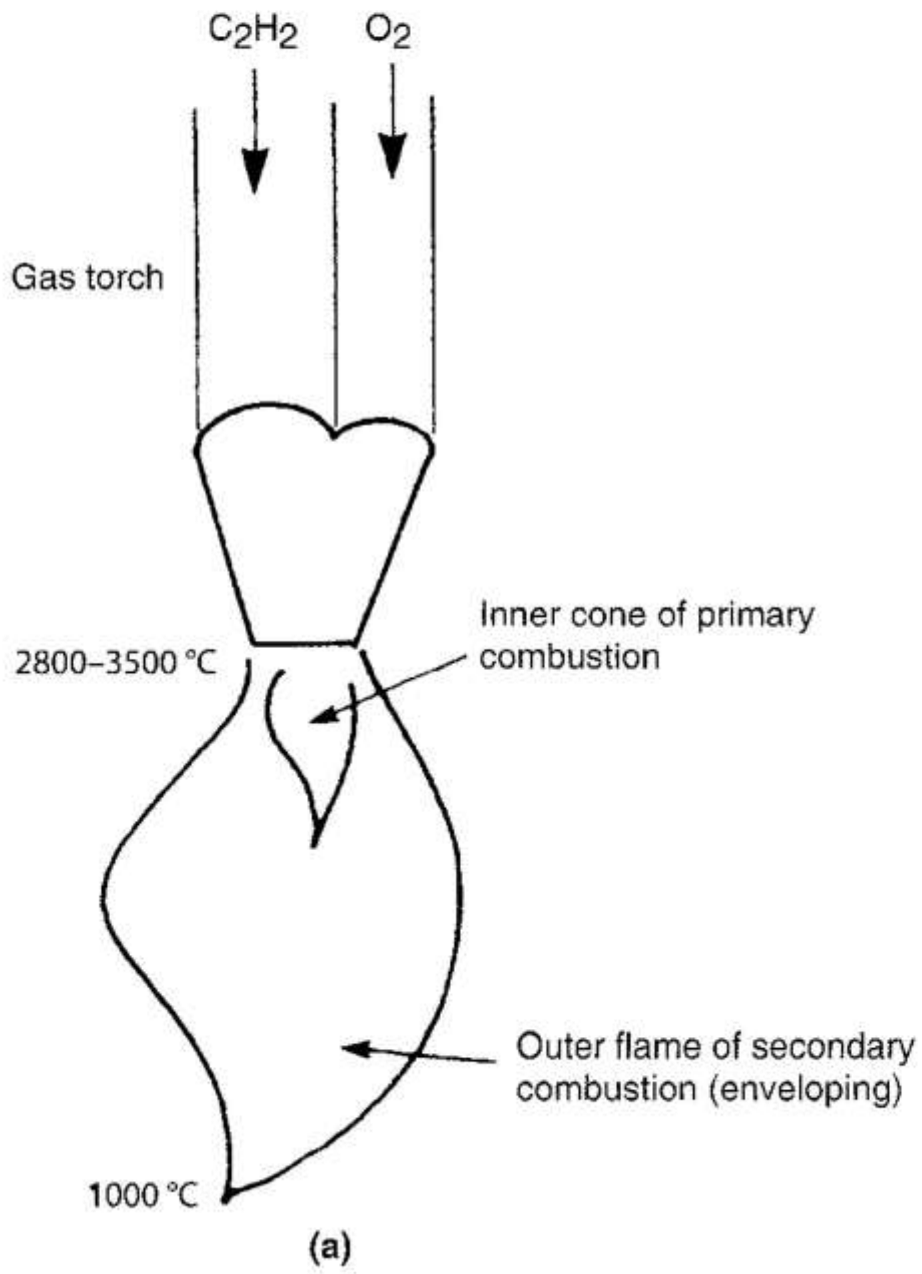


Рис. 13. Распределение удельного теплового потока q_2 пламени простой горелки по радиусу r пятна нагрева металла при угле наклона 90°:

а — схема; *б* — распределение при различных номерах наконечников (разный расход ацетилена)



$$C_2H_2(\text{cylinder}) + O_2(\text{cylinder}) > 2CO + H_2 + \Delta H(\text{enthalphy}) \qquad \text{(Eq 1)}$$

$$2CO(\text{reaction}) + H_2(\text{reaction}) + 1/2O_2(\text{air}) > 2CO_2 + 2H_2O + \Delta H \text{ enthalpy} \qquad \text{(Eq 2)}$$

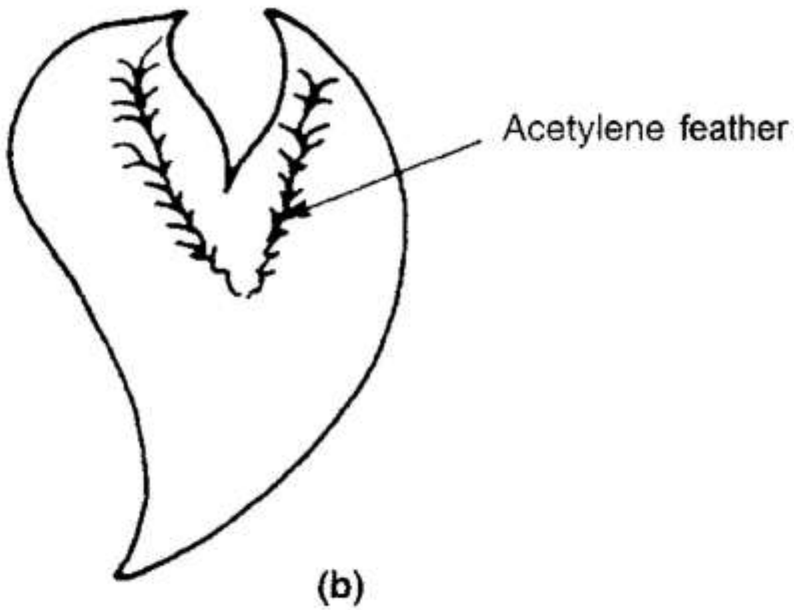
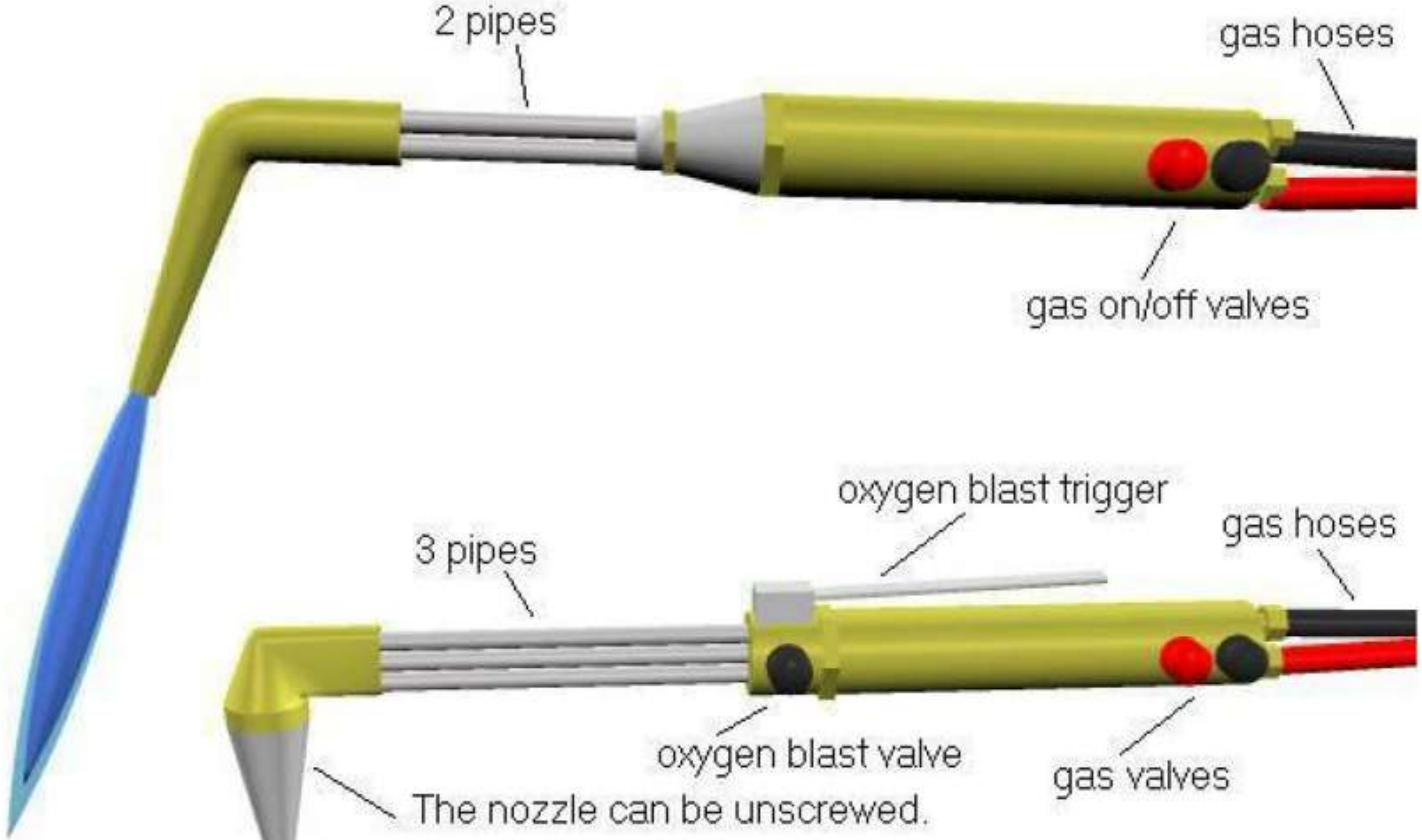
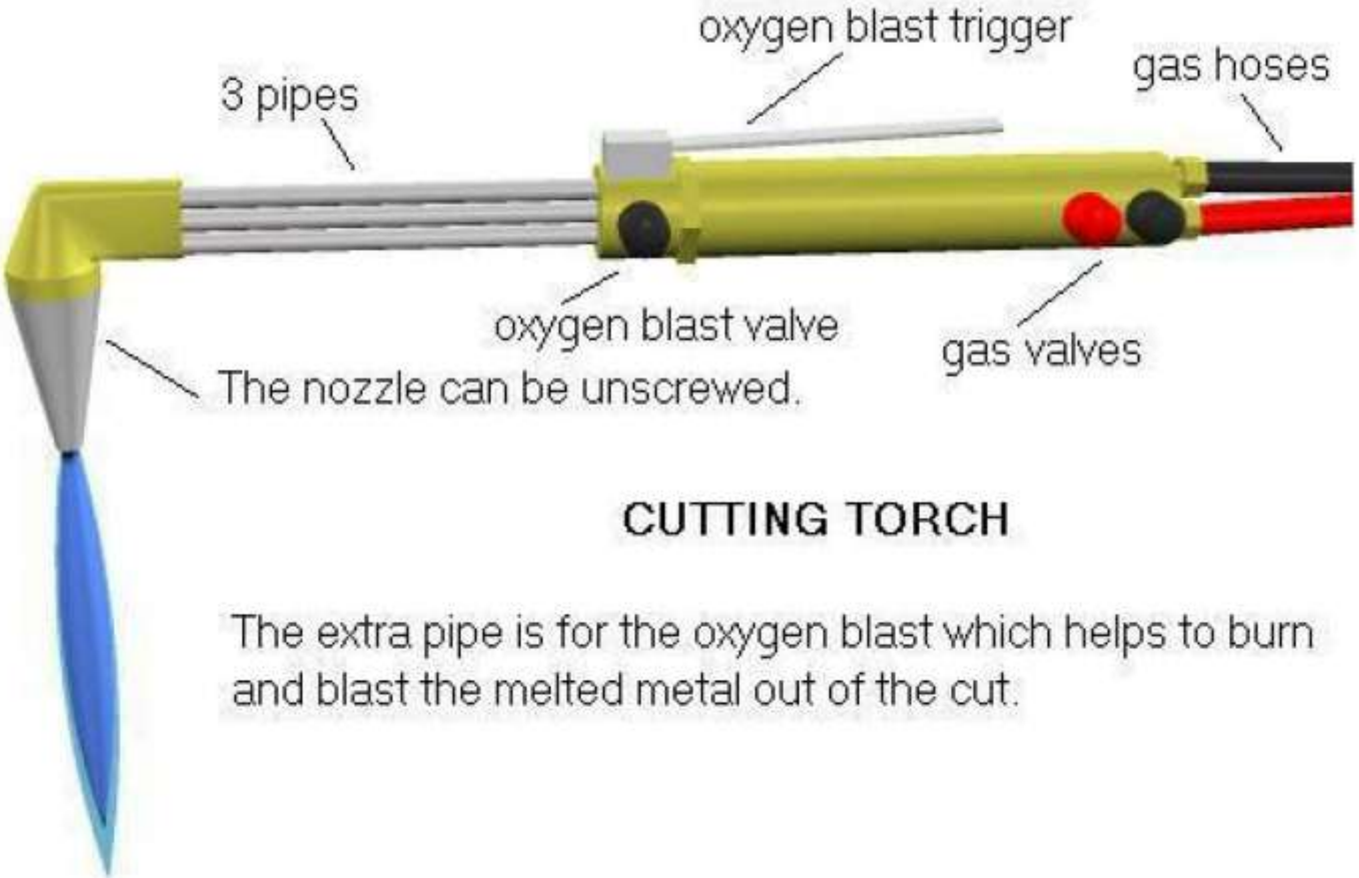


Fig. 3 Schematic illustration of a typical oxyfuel gas flame used in welding and cutting, here showing an oxyacetylene flame adjusted to be (a) neutral and (b) reducing. The primary and secondary regions of combustion are shown in (a), while the acetylene “feather” characteristic of a reducing flame is shown in (b). Source: Ref 2

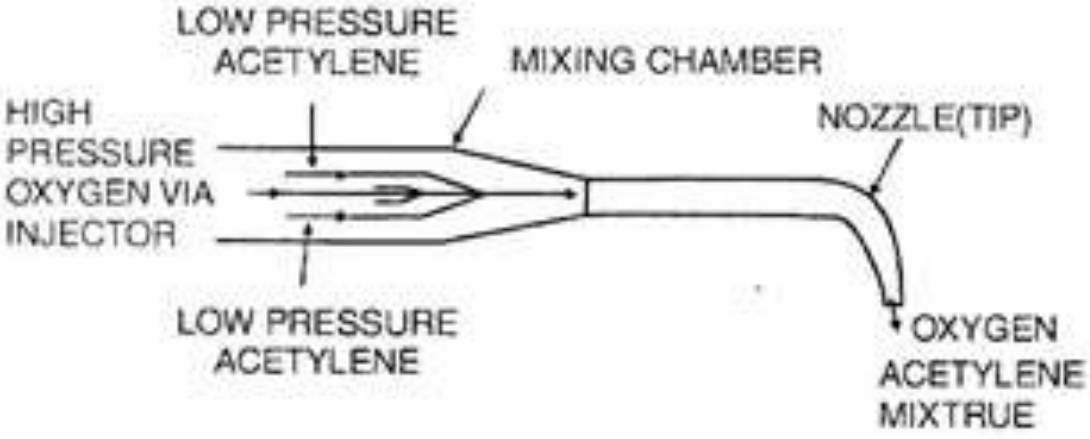
WELDING TORCH



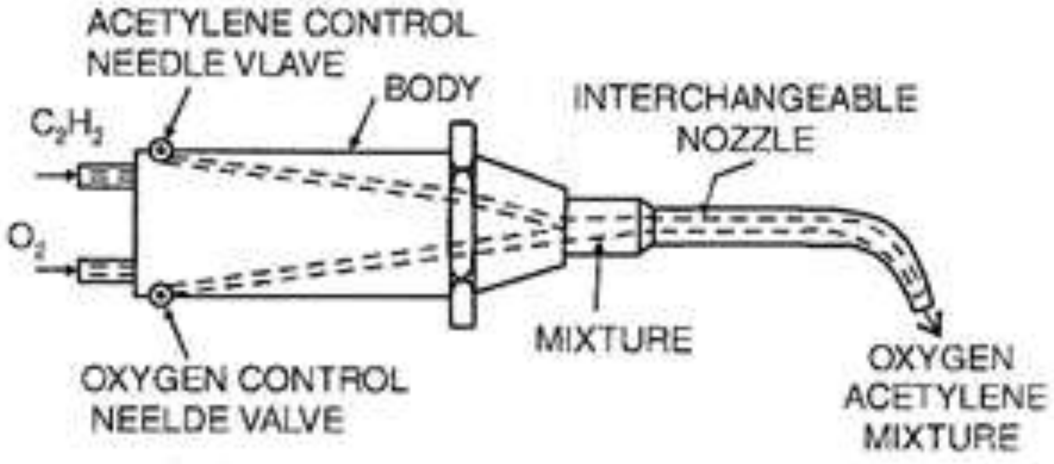


CUTTING TORCH

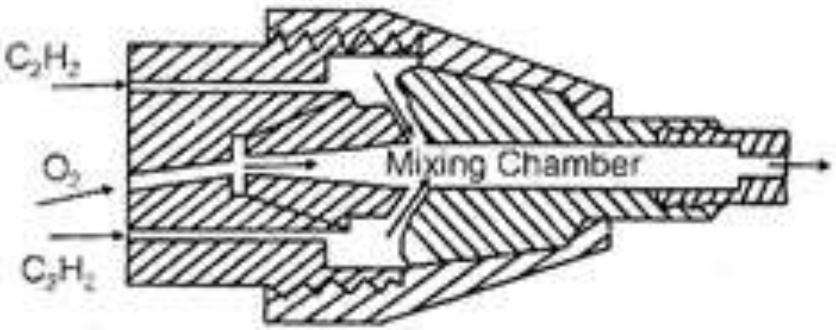
The extra pipe is for the oxygen blast which helps to burn and blast the melted metal out of the cut.



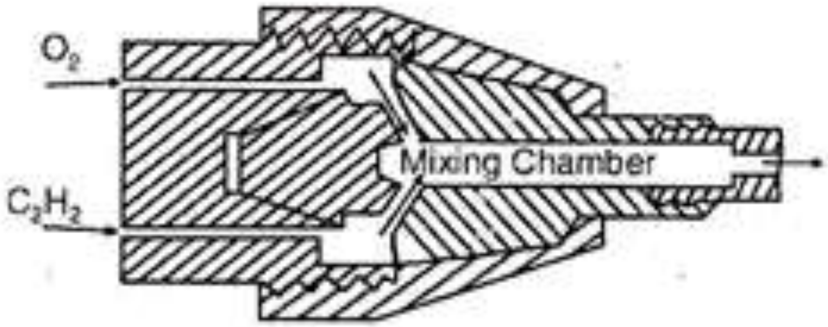
(*a*) Low pressure welding torch.



(*b*) High pressure welding torch.



(*c*) Low pressure hose connection.



(*d*) High pressure hosse connection.

Fig. 7.6.

Table : 7.2. Variation of tip diameter with thickness of work.

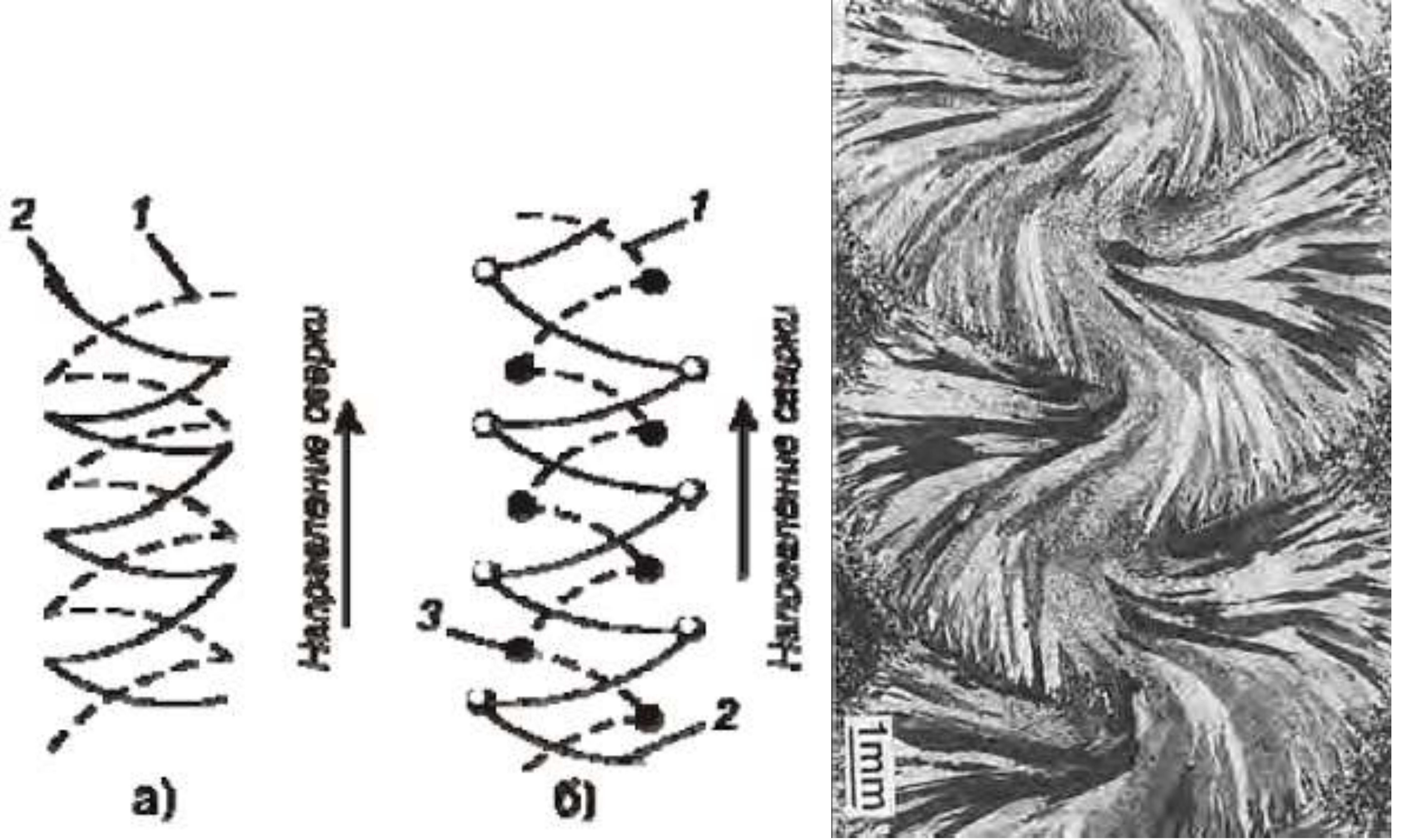
Thickness of work (mm)	Tip dia (mm)	Oxygen acetylene Pressure (bar)
0.8 mm	1mm	0.14 bar
1.6 mm	1.5 mm	0.14 bar
3.2 mm	2 mm	0.14 bar
6.4 mm	3 mm	0.20 bar
12.8 mm	4 mm	0.36 bar

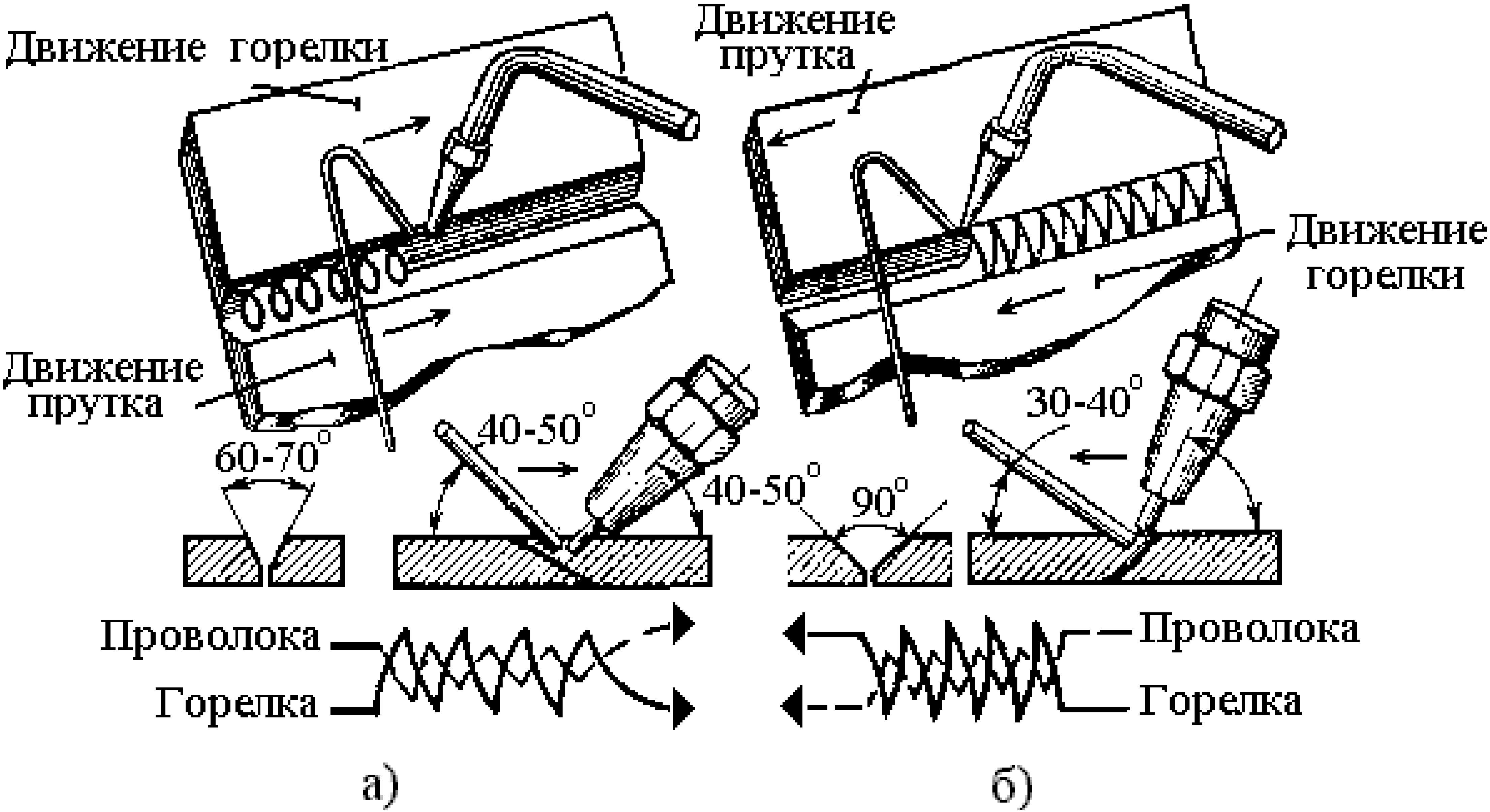
Table. 7.6. Different types of flux materials.

S.No.	Material to be weld	Flux material
1.	Ferrous metals	Borex, carbonate, bicarbonate and silicates of sodium.
2.	Copper and its alloys	Boric acid, mixture of sodium and potassium borates, carbonates, sulphates etc.
3.	Aluminium and its alloys	Alkaline chlorides, fluorides and bisulphates.
4.	Magnesium and its alloys	Same as used for aluminium and its alloys.

Table. 7.5. Different types of filler rod materials.

S.No.	Material to be weld	Filler rod material
1.	Ferrous metals	Steel rods with high carbon, silicon and magnese.
2.	Alloy steels	Steel rods with chromium and vanadium.
3.	Stainless steels	18/8 Chromium-nickel rod.
4.	Copper	Drawn copper rod.
5.	Brass	Phosphor branz rod.
6.	Grey cast iron	Special cast iron rods.
7.	Aluminium sheets and its alloys	Pure aluminium rods.
8.	Aluminium castings	Aluminium rod with 12 percent silicon.
9.	Magnesium alloys	Same composion as base material.


2
1
Направление сварки
а)
1
3
2
Направление сварки
б)
1mm



Right and left techniques of oxyfuel welding

ТЕХНОЛОГИЯ ГАЗОВОЙ СВАРКИ

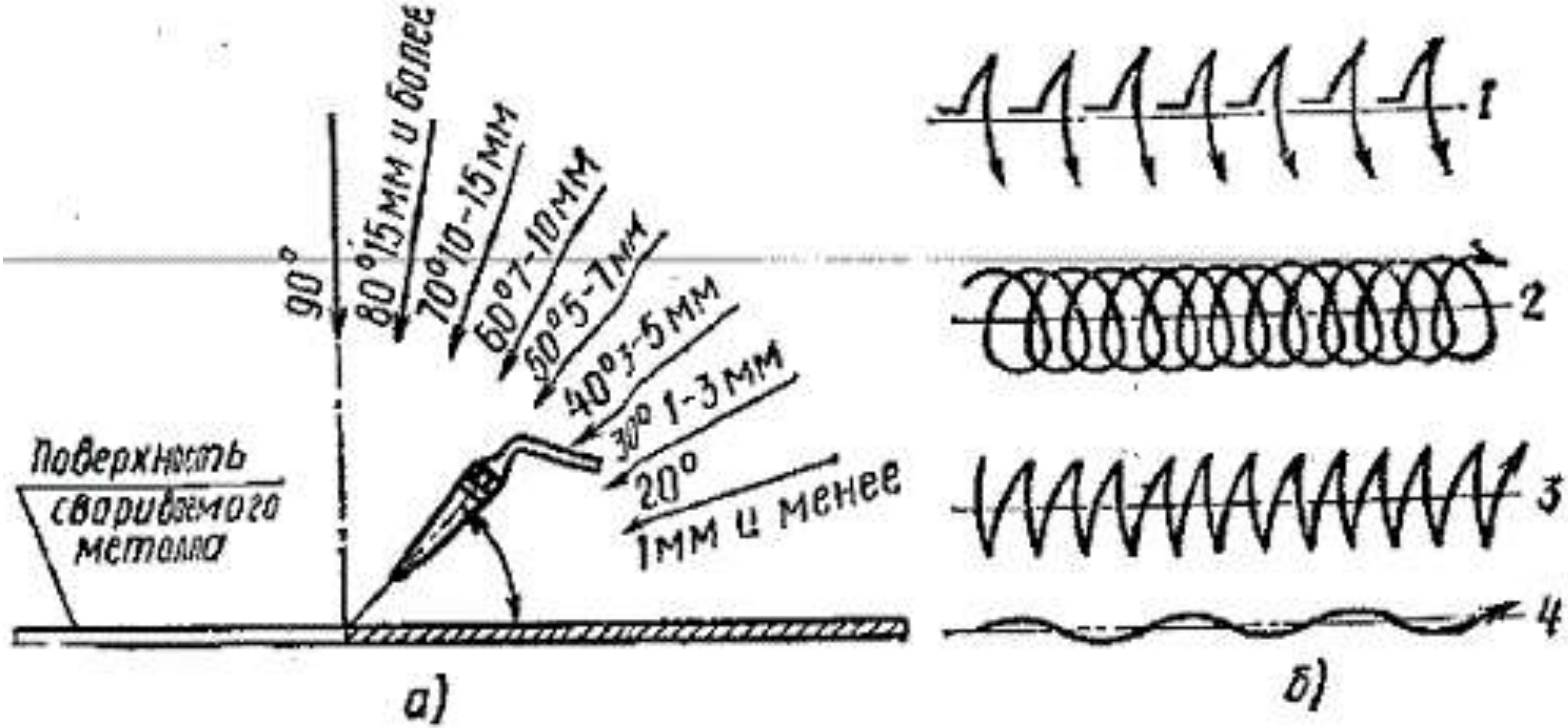
СПОСОБЫ ГАЗОВОЙ СВАРКИ

Режим сварки зависит от вида свариваемого металла, габаритов и формы изделия. К выбору сварочных режимов относятся: выбор способа сварки (левый или правый), порядок наложения шва, диаметр присадочного металла.

Качество получаемых соединений, а также производительность процесса сварки существенно зависят от мощности пламени, то есть расхода горючей смеси.

Угол наклона горелки к поверхности свариваемого металла зависит от его марки и толщины.

УГЛЫ НАКЛОНА МУНДШТУКА ГОРЕЛКИ ПРИ СВАРКЕ СТАЛИ РАЗНЫХ ТОЛЩИН



Углы наклона мундштука горелки при сварке различных толщин (а) и способы перемещения мундштука горелки (б):
1 - с отрывом горелки: 2 - спиралеобразный: 3 - полумесяцем; 4 - волнистый.

OXYFUEL GAS CUTTING (OFC).

A group of oxygen cutting processes using heat from an oxyfuel gas flame. See also oxyacetylene cutting, oxyhydrogen cutting, oxynatural gas cutting, and oxypropane cutting.

OXYACETYLENE CUTTING (OFC-A)

An oxyfuel gas cutting process variation employing acetylene as the fuel gas.

OXYHYDROGEN CUTTING (OFC-H)

An oxyfuel gas cutting process variation employing hydrogen as the fuel gas.

OXYNATURAL GAS CUTTING (OFC-N)

An oxyfuel gas cutting process variation employing natural gas as the fuel gas.

OXYPROPANE CUTTING (OFC-P)

An oxyfuel gas cutting process variation employing propane as the fuel gas

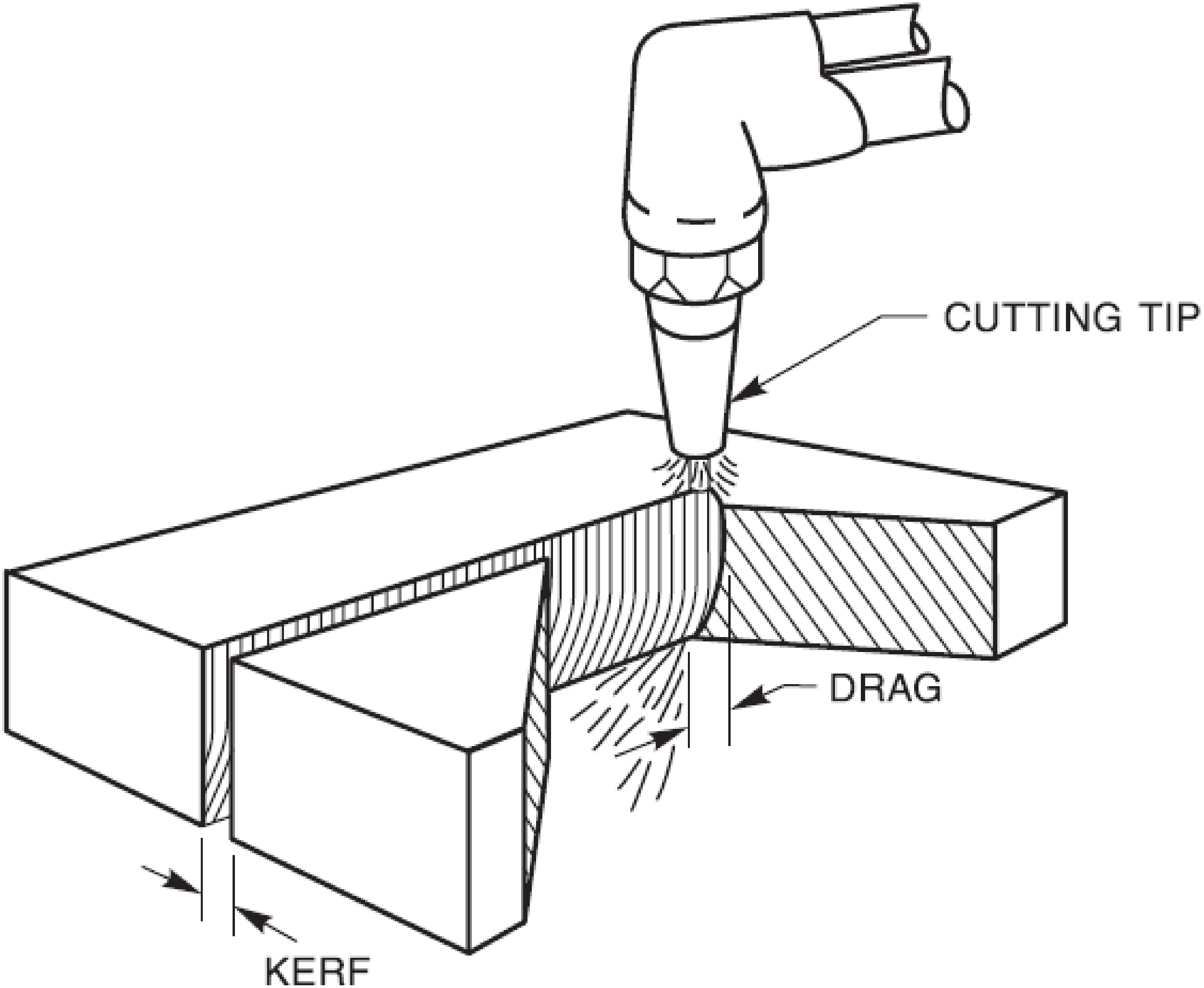
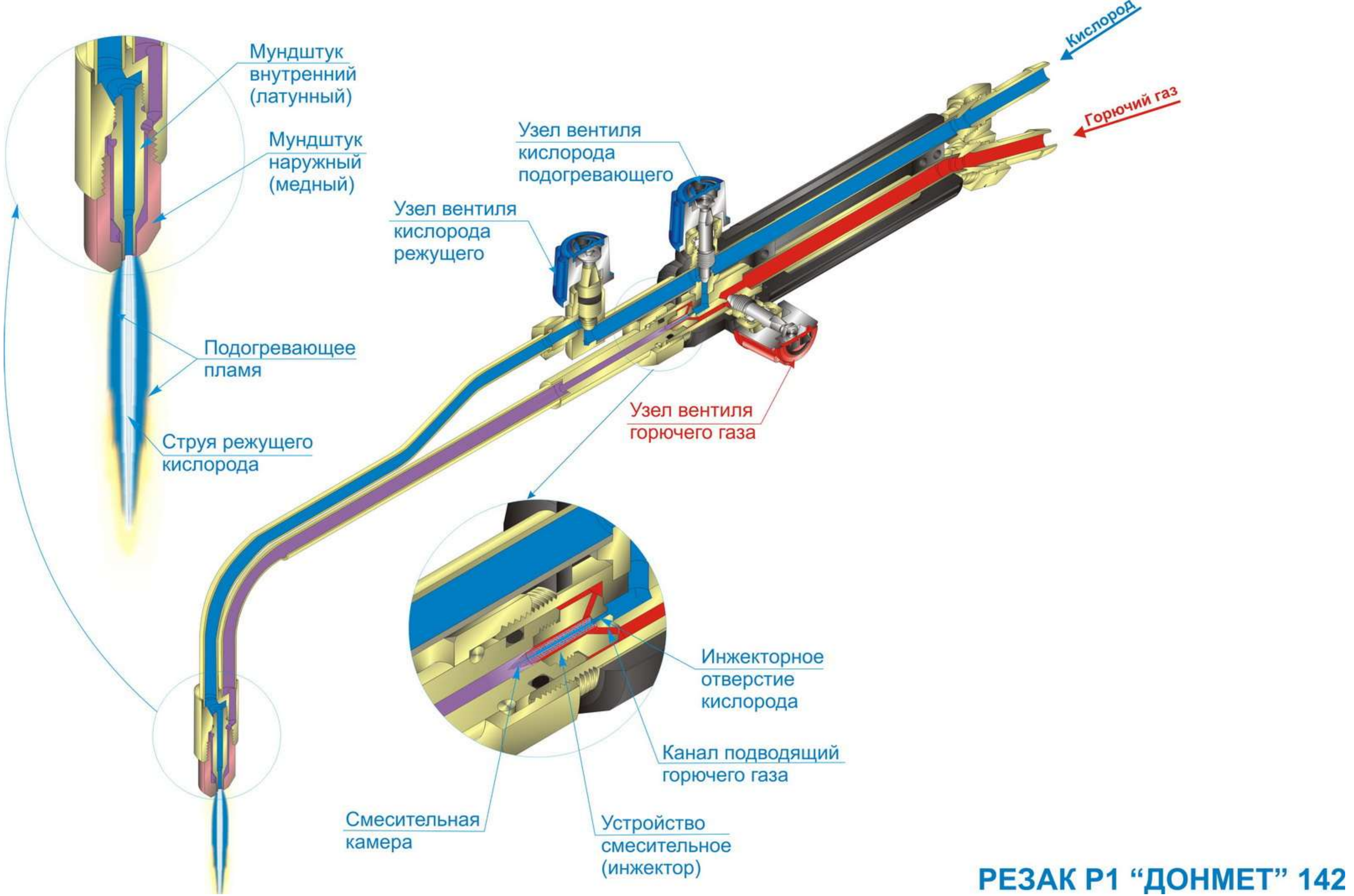


Figure B.41—Oxygen Cutting



OXYFUEL GAS WELDING TORCH

OXYFUEL GAS WELDING TORCH

A device used in oxyfuel gas welding, torch brazing, and torch soldering for directing the heating flame produced by the controlled combustion of fuel gases.

OXYFUEL GAS CUTTING TORCH

A device used for directing the preheating flame produced by the controlled combustion of fuel gases and to direct and control the cutting oxygen.

OXYFUEL GAS SPRAYING

A nonstandard term for flame spraying.

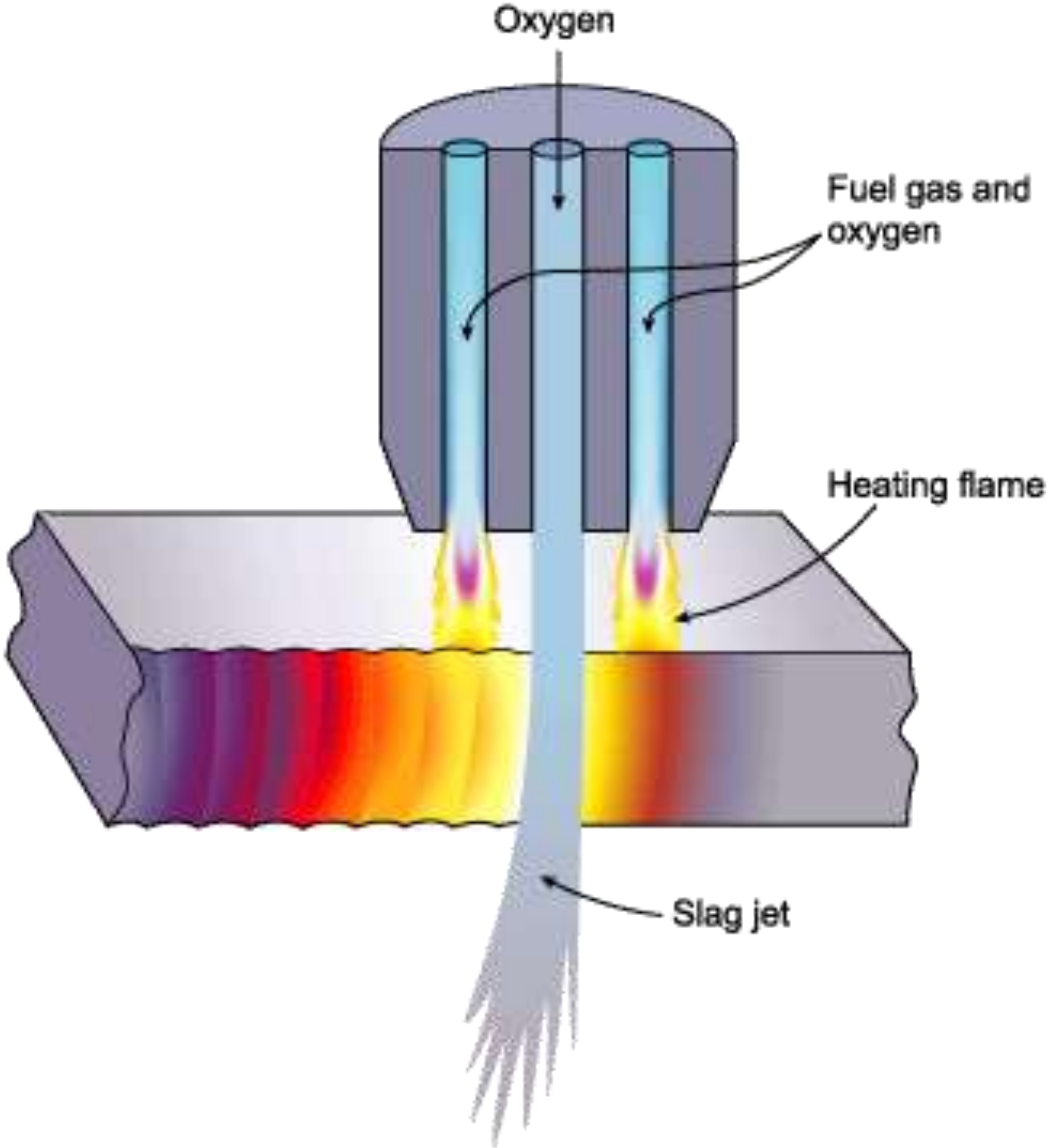
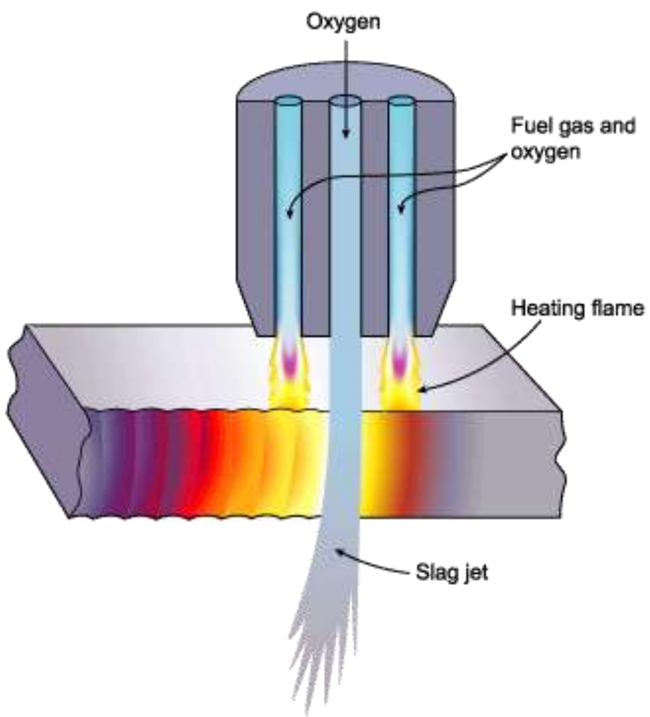


Diagram of oxyacetylene cutting process

Oxyfuel cutting - process and fuel gases

The oxyfuel cutting process is the most widely applied industrial thermal cutting process because it can cut thicknesses from 0.5mm to 250mm, the equipment is low cost and can be used manually or mechanised. There are several fuel gas and nozzle design options that can significantly enhance performance in terms of cut quality and cutting speed.

Process fundamentals



The cutting process is illustrated in *Fig. 1*. Basically, a mixture of oxygen and the fuel gas is used to preheat the metal to its 'ignition' temperature which, for steel, is 700°C - 900°C (bright red heat) but well below its melting point. A jet of pure oxygen is then directed into the preheated area instigating a vigorous exothermic chemical reaction between the oxygen and the metal to form iron oxide or slag. The oxygen jet blows away the slag enabling the jet to pierce through the material and continue to cut through the material.

There are **four basic requirements** for oxy-fuel cutting:

- ✓ the ignition temperature of the material must be lower than its melting point otherwise the material would melt and flow away before cutting could take place
- ✓ the oxide melting point must be lower than that of the surrounding material so that it can be mechanically blown away by the oxygen jet
- ✓ the oxidation reaction between the oxygen jet and the metal must be sufficient to maintain the ignition temperature
- ✓ a minimum of gaseous reaction products should be produced so as not to dilute the cutting oxygen

As stainless steel, cast iron and non-ferrous metals form refractory oxides ie the oxide melting point is higher than the material, powder must be injected into the flame to form a low melting point, fluid slag.

Purity of oxygen

The cutting speed and cut edge quality are primarily determined by the purity of the oxygen stream. Thus, nozzle design plays a significant role in protecting the oxygen stream from air entrainment.

The purity of oxygen should be at least 99.5%. A decrease in purity of 1% will typically reduce the cutting speed by 25% and increase the gas consumption by 25%.

Choice of fuel gas

Fuel gas combustion occurs in two distinct zones. In the inner cone or primary flame, the fuel gas combines with oxygen to form carbon monoxide and hydrogen which for acetylene, the reaction is given by

$$2C_2H_2 + 2O_2 \rightarrow 4CO + 2H_2$$

Combustion also continues in the secondary or outer zone of the flame with oxygen being supplied from the air.

$$4CO+2H_2+3O_2 \rightarrow 4CO_2+2H_2O$$

Thus, fuel gases are characterised by their

- ✓ flame temperature - the hottest part of the flame is at the tip of the primary flame (inner cone)
- ✓ fuel gas to oxygen ratio - the amount of fuel gas required for combustion but this will vary according to whether the flame is neutral, oxidising or reducing
- ✓ heat of combustion - heat of combustion is greater in the outer part of the flame

The five most commonly used fuel gases are acetylene, propane, MAPP (methylacetylene-propadiene), propylene and natural gas. The properties of the gases are given in the Table. The relative performance of the fuel gases in terms of pierce time, cutting speed and cut edge quality, is determined by the flame temperature and heat distribution within the inner and out flame cones.

Acetylene

Acetylene produces the highest flame temperature of all the fuel gases. The maximum flame temperature for acetylene (in oxygen) is approximately 3,160°C compared with a maximum temperature of 2,828°C with propane. The hotter flame produces more rapid piercing of the materials with the pierce time being typically one third that produced with propane.

The higher flame speed (7.4m/s compared with 3.3m/s for propane) and the higher calorific value of the primary flame (inner cone) (18,890 kJ/m3 compared with 10,433 kJ/m3 for propane) produce a more intense flame at the surface of the metal reducing the width of the Heat Affected Zone (HAZ) and the degree of distortion.

Propane

Propane produces **a lower flame temperature than acetylene** (the maximum flame temperature in oxygen is 2,828°C compared with 3,160°C for acetylene). It has a greater total heat of combustion than acetylene but the heat is generated mostly in the outer cone (*see Table*). The characteristic appearance of the flames for acetylene and propane are shown in *Figs.2 and 3* where the propane flame appears to be less focused. Consequently, piercing is much slower but as the burning and slag formation are effected by the oxygen jet, cutting speeds are about the same as for acetylene.

Propane has a greater stoichiometric oxygen requirement than acetylene; for the maximum flame temperature in oxygen, the ratio of the volume of oxygen to fuel gas are 1.2 to 1 for acetylene and 4.3 to 1 for propane.

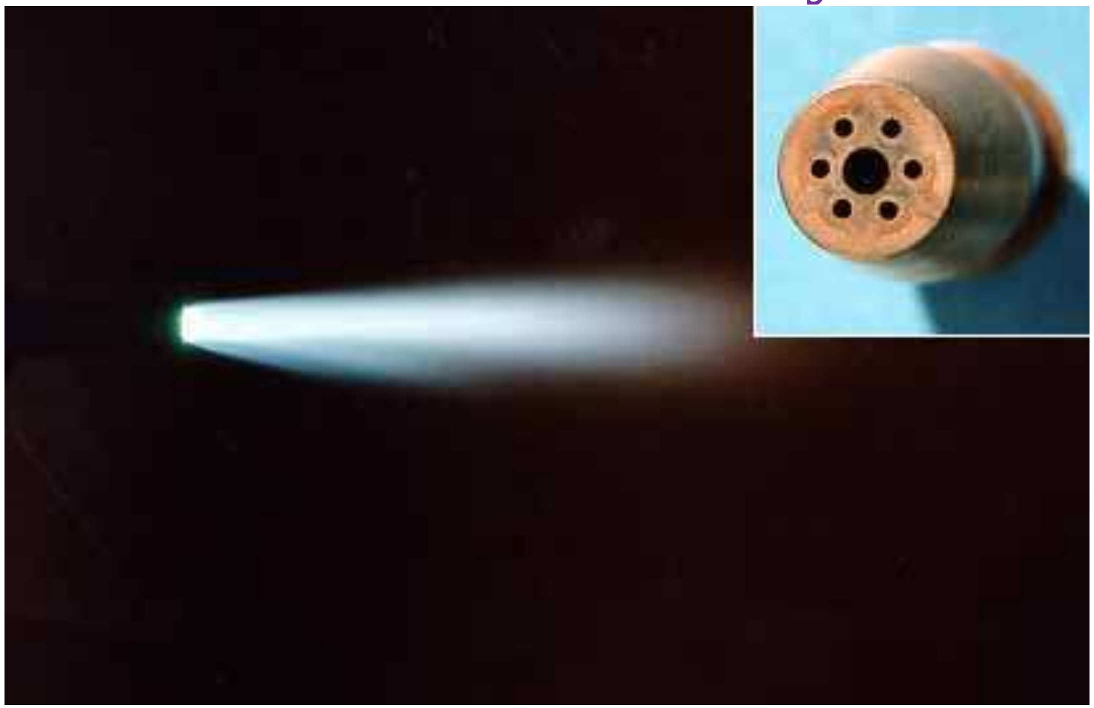


Fig.2. Ocyacetylene gas jet and nozzle design

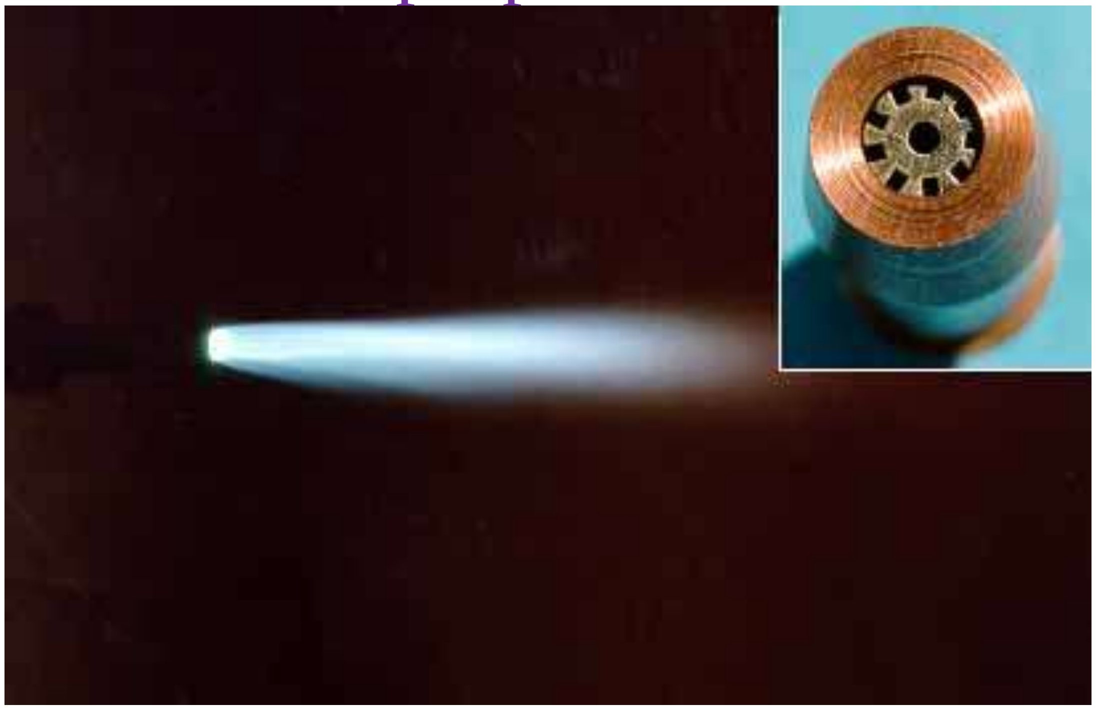


Fig.3. Propane gas jet and nozzle design

MAPP

MAPP gas is a mixture of various hydrocarbons, principally, methylacetylene and propadiene. It produces a relatively hot flame (2,976°C) with a high heat release in the primary flame (inner cone) (15,445kJ/m3), less than for acetylene (18,890kJm3) but much higher than for propane (10,433kJm3). The secondary flame (outer cone) also gives off a high heat release, similar to propane and natural gas. The combination
of a lower flame temperature, more distributed heat source and larger gas flows compared with acetylene results in a substantially slower pierce time.

As MAPP gas can be used at a higher pressure than acetylene, it can be used for underwater cutting in deep water as it is less likely to dissociate into its components of carbon and hydrogen which are explosive.

Propylene

Propylene is a liquid petroleum gas (LPG) product and has a similar flame temperature to MAPP (2896°C compared to 2,976°C for

MAPP); it is hotter than propane, but not as hot as acetylene. It gives off a high heat release in the outer cone (72,000kJ/m3) but, like propane, it has the disadvantage of having a high stoichiometric fuel gas requirement (oxygen to fuel gas ratio of approximately 3.7 to 1 by volume).

Natural Gas

Natural gas has the lowest flame temperature similar to propane and the lowest total heat value of the commonly used fuel gases, eg for the inner flame 1,490kJ/m3 compared with 18,890kJ/m3 for acetylene. Consequently, natural gas is the slowest for piercing.

Fuel Gas Characteristics

Fuel Gas	Maximum Flame Temperature °C	Oxygen to fuel gas Ratio (vol)	Heat distribution kJ/m3	
			Primary	Secondary
Acetylene	3,160	1.2:1	18,890	35,882
Propane	2,828	4.3:1	10,433	85,325
MAPP	2,976	3.3:1	15,445	56,431
Propylene	2,896	3.7:1	16,000	72,000
Hydrogen	2,856	0.42:1	-	-
Natural Gas	2,770	1.8:1	1,490	35,770

For further information contact arc@twi.co.uk

This Job Knowledge article was originally published in Connect, September/October 2000. It has been updated so the web page no longer reflects exactly the printed version.

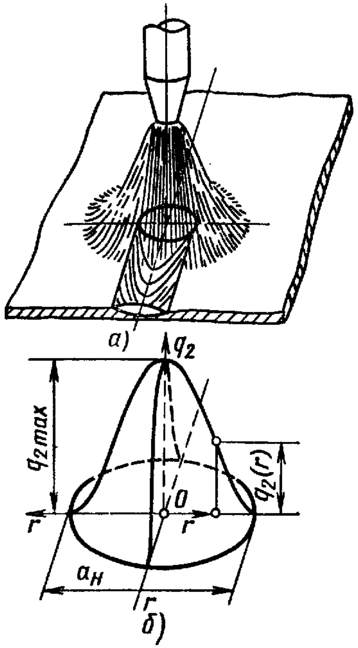


Рис. 1. Схема сварочной дуги как источника теплоты:

а — столб и пламя дуги; *б* — схема распределения теплового потока дуги (нормально-круговой источник) участкам поверхности металла.

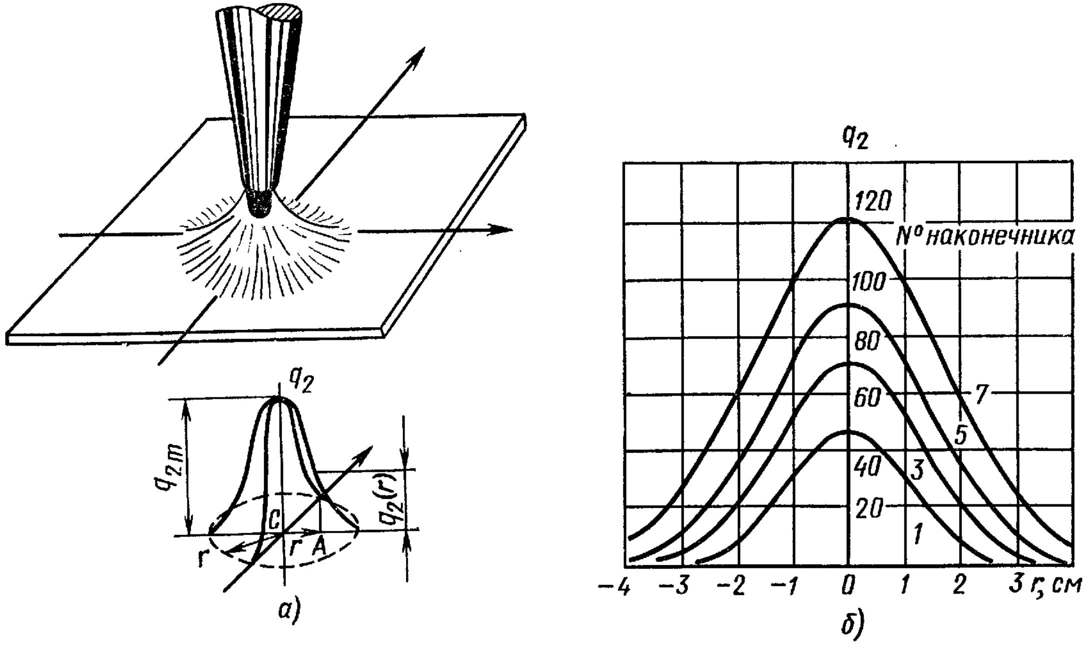


Рис. 13. Распределение удельного теплового потока q_2 пламени простой горелки по радиусу r пятна нагрева металла при угле наклона 90°:

а — схема; *б* — распределение при различных номерах наконечников (разный расход ацетилена)

МЕТАЛЛУРГИЧЕСКИЕ РЕАКЦИИ ПРИ СВАРКЕ

При сварке без защиты расплавляемый металл интенсивно поглощает азот и кислород из воздуха, вследствие чего сварные швы характеризуются низкими механическими свойствами (табл. 1).

1. **Характеристика металла сварного шва**

Наименование показателей	Основной металл (сталь Ст3)	Металл шва при сварке проволокой Св-08А
Содержание кислорода, %	До 0,02	0,1—0,2
Содержание азота, %	0,04—0,08	0,1—0,2
Предел прочности, кгс/мм²	40—45	34—40
Относительное удлинение, %	25—30	5—10
Угол загиба, градусы	180	20—40
Ударная вязкость, кгс · м/см²	> 15	0,5—2,5

го влияния.

В общем плане несвариваемых материалов нет, однако чем хуже свариваемость материала, тем сложнее технология сварки, тем больше мероприятий необходимо применять для получения качественного сварного соединения.

ARC WELDING

Class: Fusion Welding
Energy Source: Electrical type - Electrical arc

ARC WELDING (AW)

A group of welding processes producing coalescence of workpieces by melting them with an arc. The processes are used with or without the application of pressure and with or without filler metal. AWS A3.0M/A3.0:2010

WELDING ARC

A controlled electrical discharge between the electrode and the workpiece formed and sustained by the establishment of a gaseous conductive medium, called an arc plasma.

ARC WELDING ELECTRODE

A component of the welding circuit through which current is conducted and that terminates at the arc.

ARC WELDING GUN

A device used to transfer current to a continuously fed consumable electrode, guide the electrode, and direct the shielding gas. See Figure B.38.

ARC WELDING TORCH

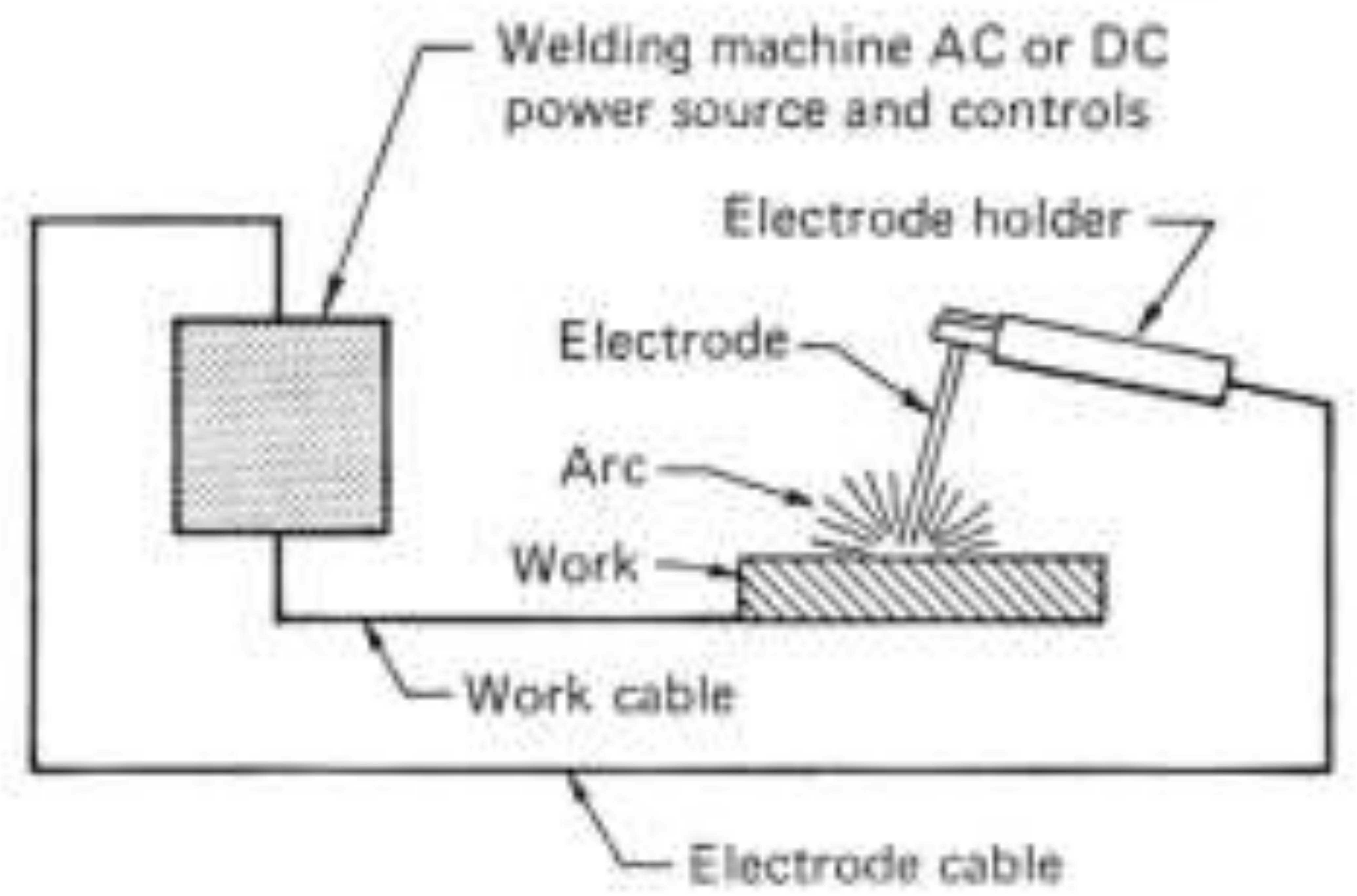
A device used to transfer current to a fixed welding electrode, position the electrode, and direct the shielding gas. See Figures B.35 and B.36.

ARC TIME

The time during which an arc is maintained in making an arc weld.

ARC VOLTAGE, ***ARC WELDING.***

The electrical potential between the electrode and workpiece.



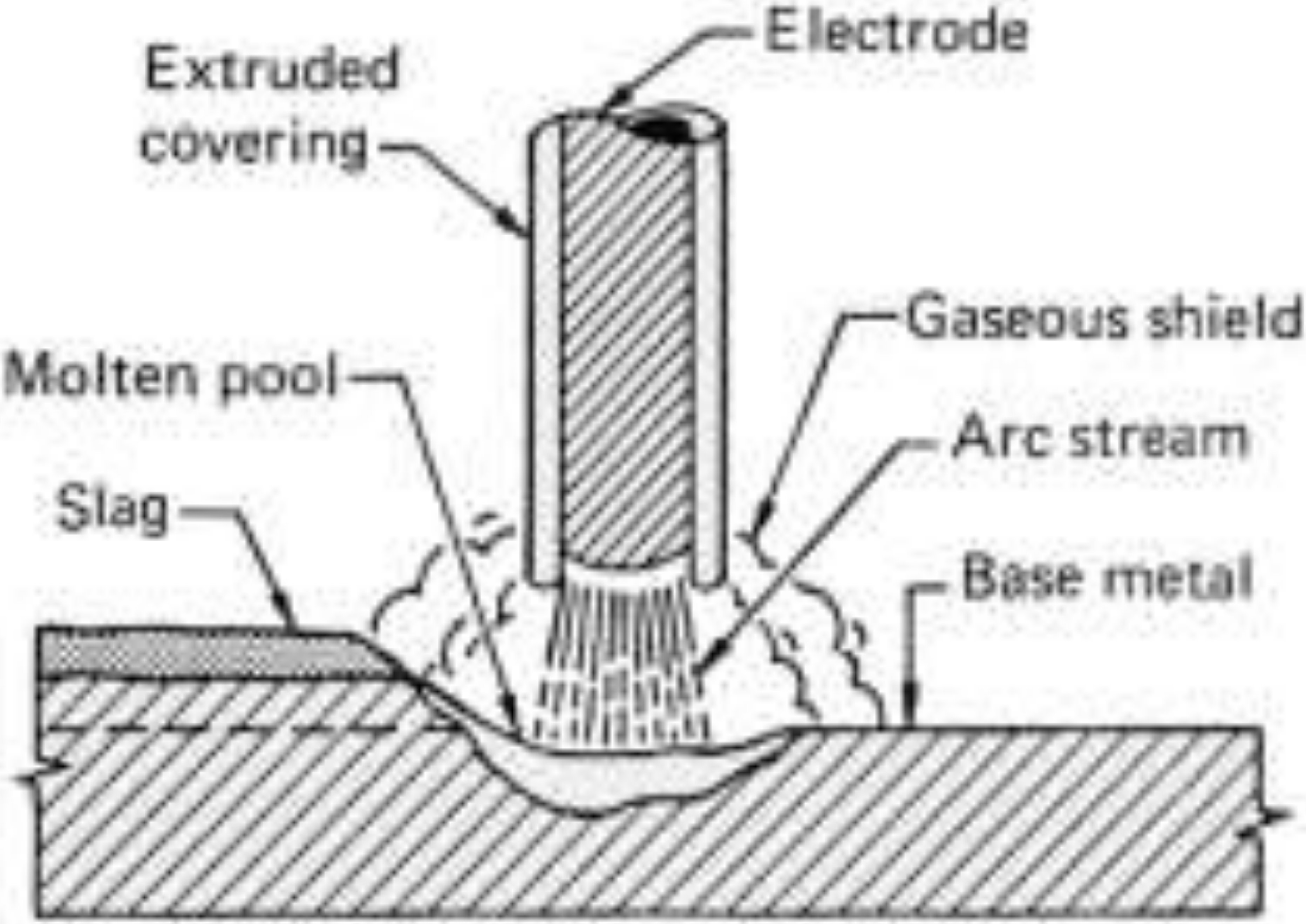
http://www.lincolnelectric.com/en-us/support/process-and-theory/Pages/arc-welding-detail.aspx

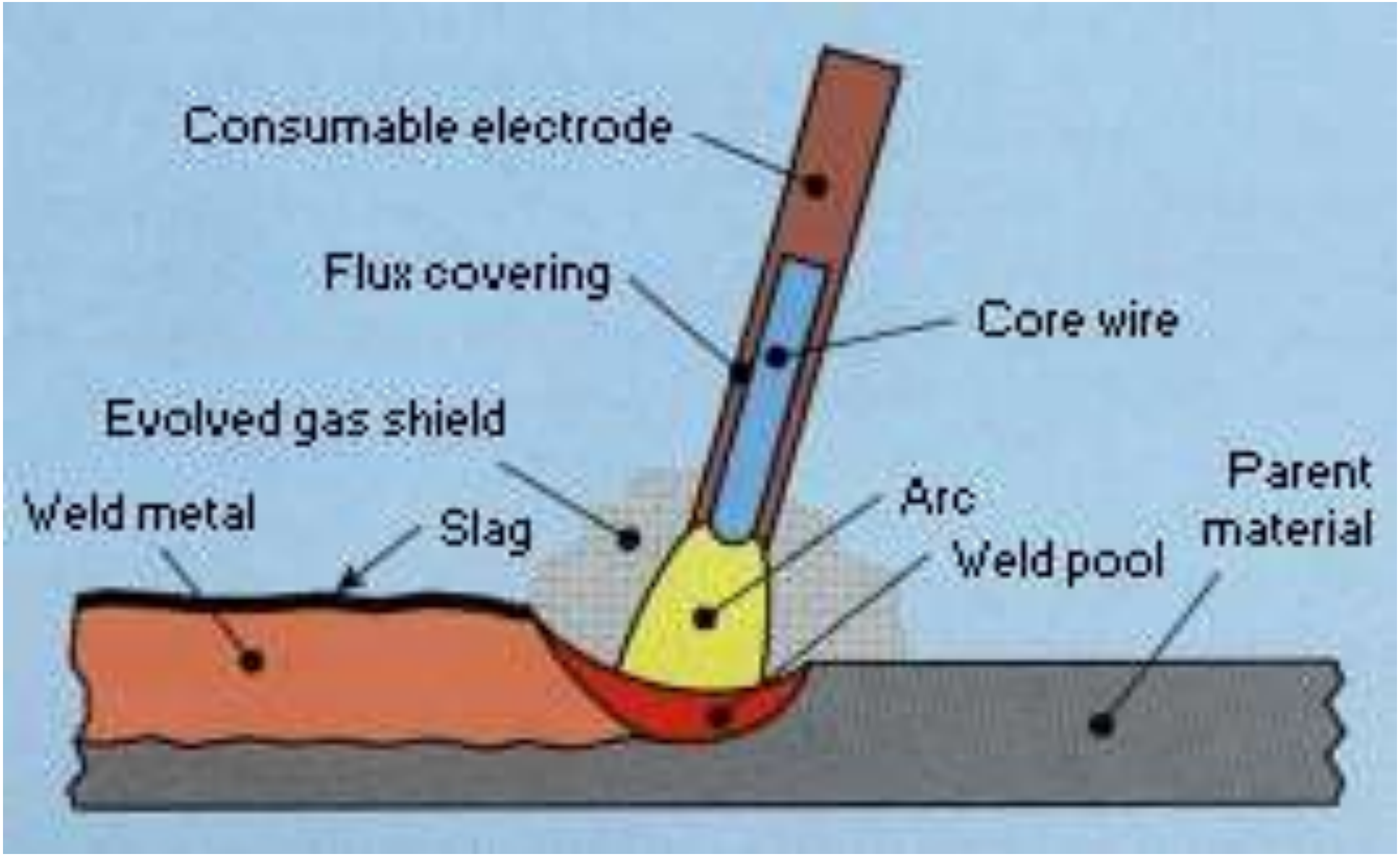
Arc welding is one of several fusion processes for joining metals. By applying intense heat, metal at the joint between two parts is melted and caused to intermix – directly, or more commonly, with an intermediate molten filler metal. Upon cooling and solidification, a metallurgical bond is created.

In arc welding, the intense heat needed to melt metal is produced by an electric arc. The arc is formed between the base (parent) metal and an electrode (stick or wire) that is guided along the joint. The electrode

either can be a rod with the purpose of simply carrying the current between the tip and the work.

or it may be a specially prepared rod or wire that not only conducts the current but also melts and supplies filler metal to the joint.


Electrode
Extruded covering
Gaseous shield
Molten pool
Arc stream
Slag
Base metal


Consumable electrode
Flux covering
Core wire
Evolved gas shield
Weld metal
Slag
Arc
Parent material
Weld pool

An arc is an electric current flowing between two electrodes through an ionized column of gas. A negatively charged **cathode** and a positively charged **anode** create the intense heat of the welding arc. Negative and positive ions are bounced off of each other in the plasma column at an accelerated rate.

In welding, the ***arc not only provides the heat*** needed to melt the electrode and the base metal, but under certain conditions must also supply the means to ***transport the molten metal from the tip of the electrode to the work***.

So, **electrode** may be

- ***consumable***
- ***non-consumable*** (carbon, tungsten TIG)

If an electrode is ***consumable***, the tip melts under the heat of the arc and molten droplets are detached and transported to the work through the arc column. Any arc welding system in which the electrode is melted off to become part of the weld is described as ***metal-arc***.

In case of carbon or tungsten (TIG) welding there are no molten droplets to be forced across the gap and onto the work. Filler metal is melted into the joint from a separate rod or wire.

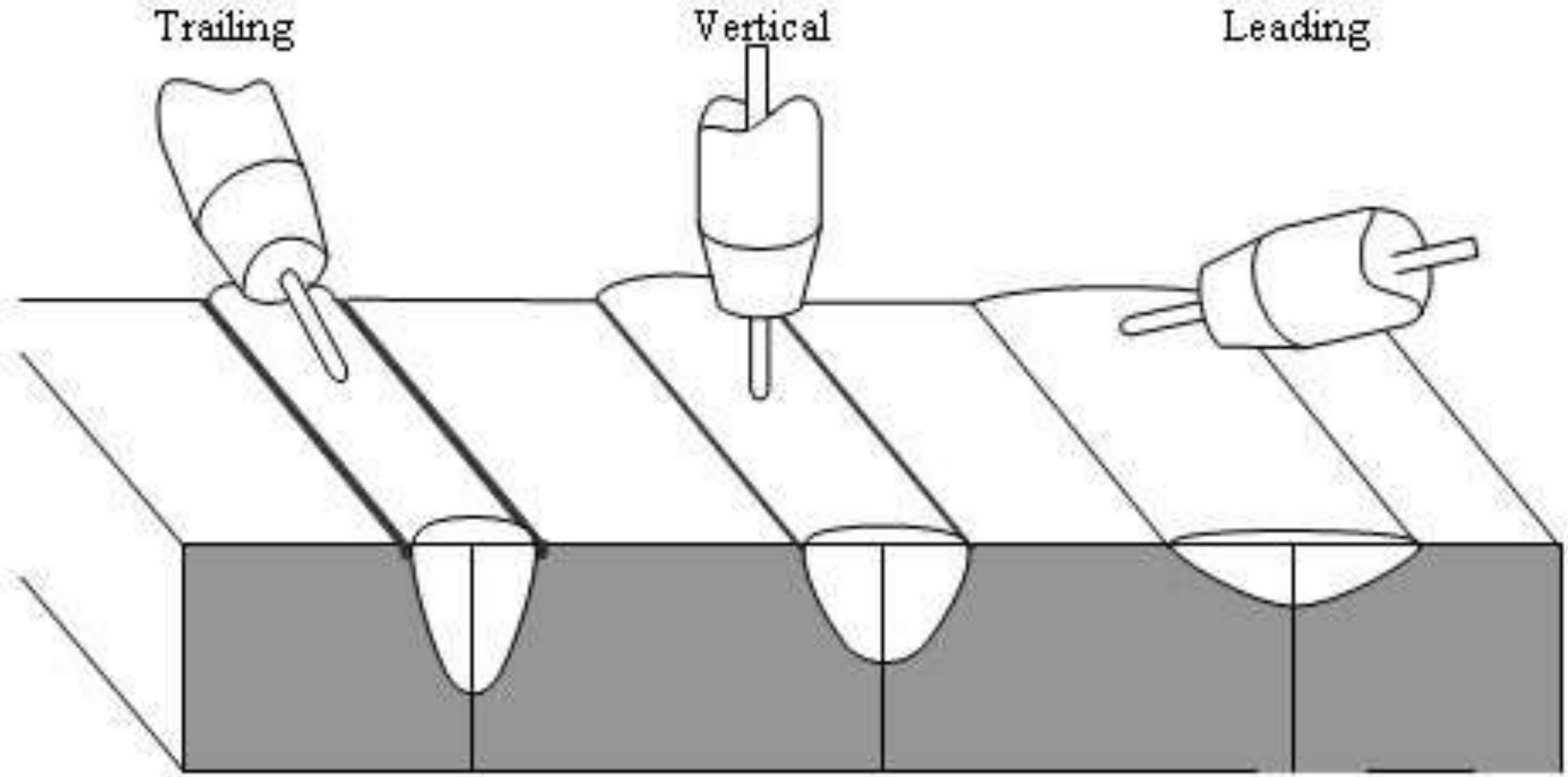
More of the heat developed by the arc is transferred to the weld pool with ***consumable electrodes***. ***This produces higher thermal efficiencies and narrower heat-affected zones.***

Arc welding may be done with

- direct current (DC) with the electrode
  - ✓ positive
  - ✓ negative
- alternating current (AC).

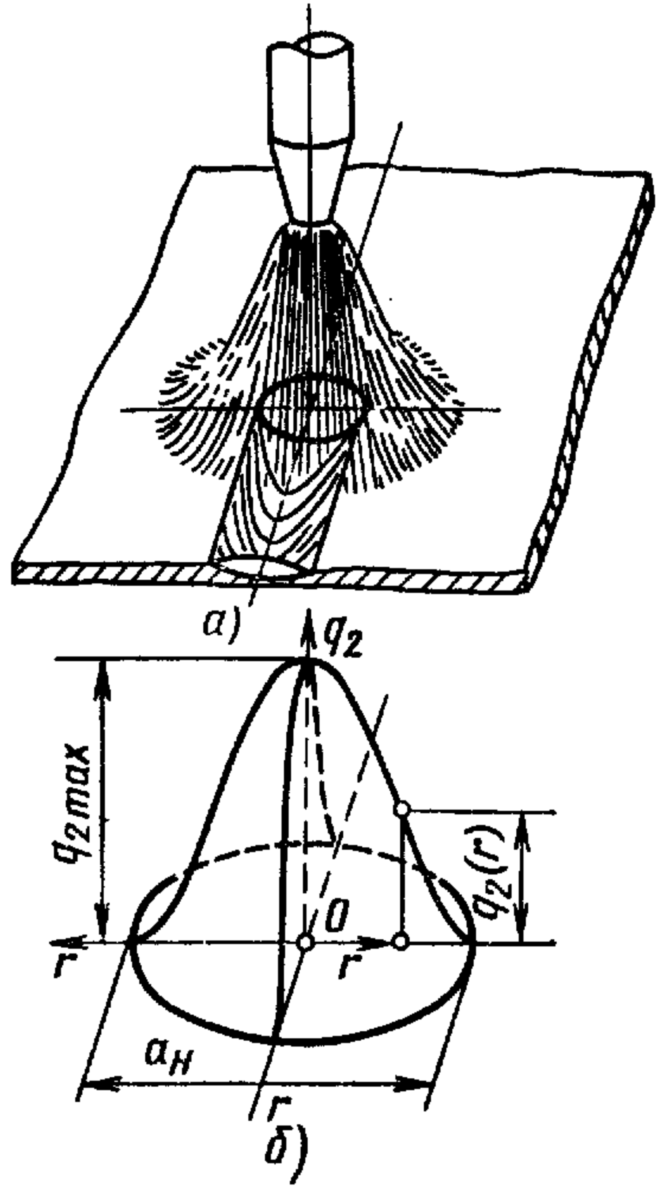
The choice of current and polarity depends on

- ✓ the process,
- ✓ the type of electrode,
- ✓ the arc atmosphere,
- ✓ the metal being welded.



Penetration:	Deep	Moderate	Shallow
Reinforcement:	Maximum	Moderate	Minimum
Tendency to undercut:	Severe	Moderate	Minimum

Effect of electrode angle on butt welds.



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Schematic diagram of P.A.W.