Two Days Course on

METALLURGY FOR PRACTICING ENGINEERS (MEPE-2020)

Lecture on

MATERIALS JOINING TECHNOLOGIES

by

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AGNEDA FOR TODAY'S LECTURE

- **PHASE 1:** FUSION WELDING PROCESSES
- **PHASE 2:** SOLID STATE WELDING PROCESSES
- **PHASE 3:** CASE STUDIES
- **PHASE 4:** ABOUT MY INSTITUTION
- **PHASE 5:** QUESTION & ANSWER SESSION

PHASE 1:

FUSION WELDING PROCESSES

What is meant by Welding?

- Joining of two materials by means of
  - Heat
  - Pressure
  - Heat & Pressure

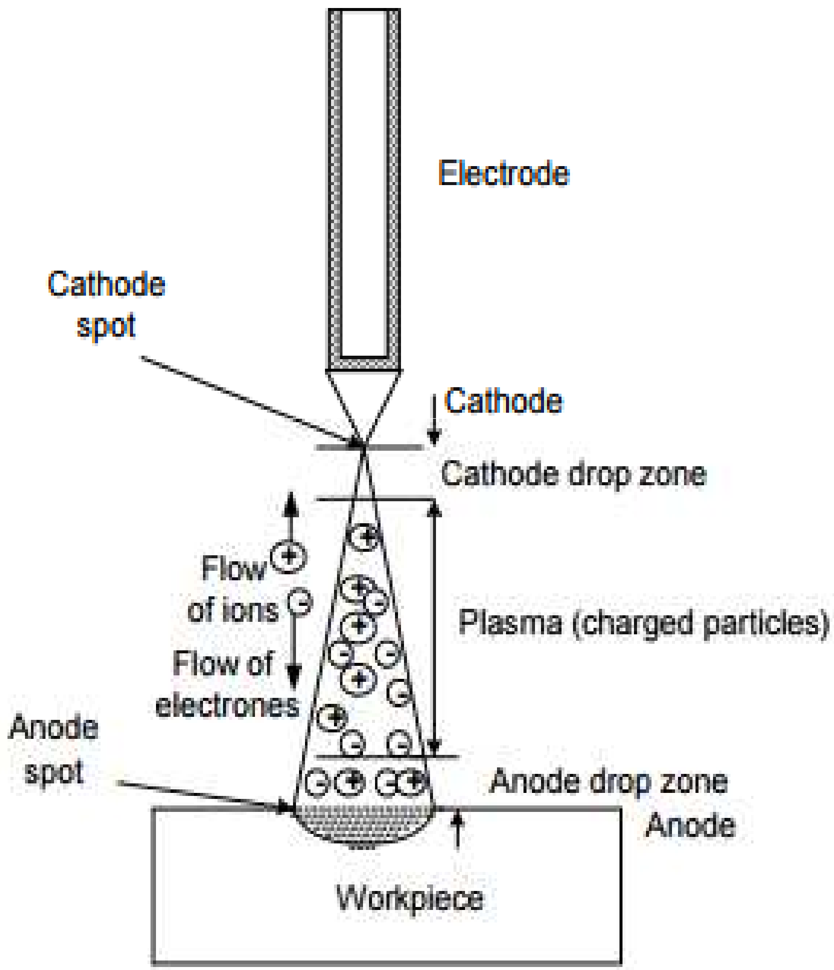
Production of Heat for Joining

- Gas Flame
- Electric Arc
- Laser Beam
- Electron Beam
- Chemical Reactions

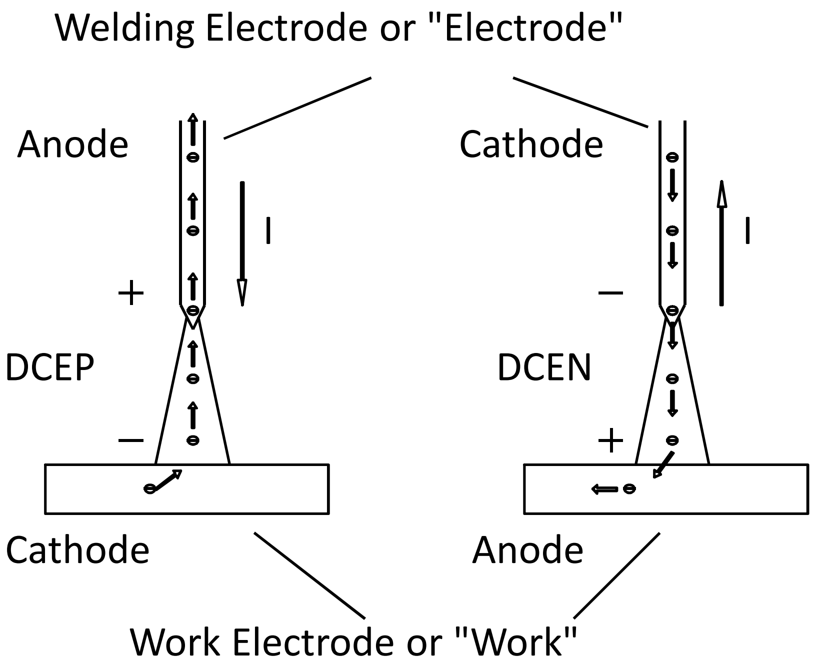
ZONES IN WELDING ARC

- **Generally, five different zones are observed in the arc gap namely**

- ***cathode spot,***
- ***cathode drop zone,***
- ***plasma,***
- ***anode drop zone***
- ***anode spot***



POLARITY AND CURRENT FLOW



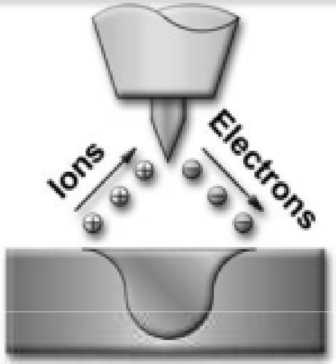
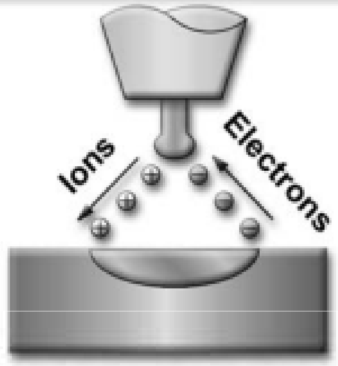
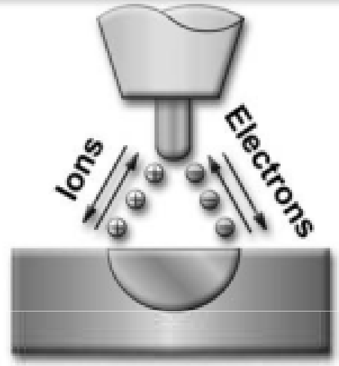
Reverse
RPEP

Straight
SPEN

In case of direct current (DC) welding, when electrode is connected to the negative terminal and workpiece is connected with positive terminal as direct current electrode negative polarity (DCEN) or straight polarity

Electrode is connected to the positive terminal of the power source and workpiece is connected with negative terminal then it is termed as direct current electrode positive polarity (DCEP) or reverse polarity.

CURRENT CHARACTERISTICS

Current Type	DCEN	DCEP	AC (Balanced)
Electrode Polarity	Negative	Positive	
Electron and Ion Flow Penetration Characteristics			
Oxide Cleaning Action	No	Yes	Yes-Once Every Half Cycle
Heat Balance In The Arc (Approx.)	70% At Work End 30% At Electrode End	30% At Work End 70% At Electrode End	50% At Work End 50% At Electrode End
Penetration	Deep; Narrow	Shallow; Wide	Medium
Electrode Capacity	Excellent 1/8" (3.2mm) 400 A	Poor 1/4" (6.4mm) 120 A	Good 1/8" (3.2mm) 225 A

Characteristics Of Current Types For Gas Tungsten Arc Welding

ARC WELDING PROCESSES

(A) Consumable Arc Welding Processes:

(i) Shielded Metal Arc Welding (SMAW)

(ii) Gas Metal Arc Welding (GMAW)

(iii) Flux Cored Arc Welding (FCAW)

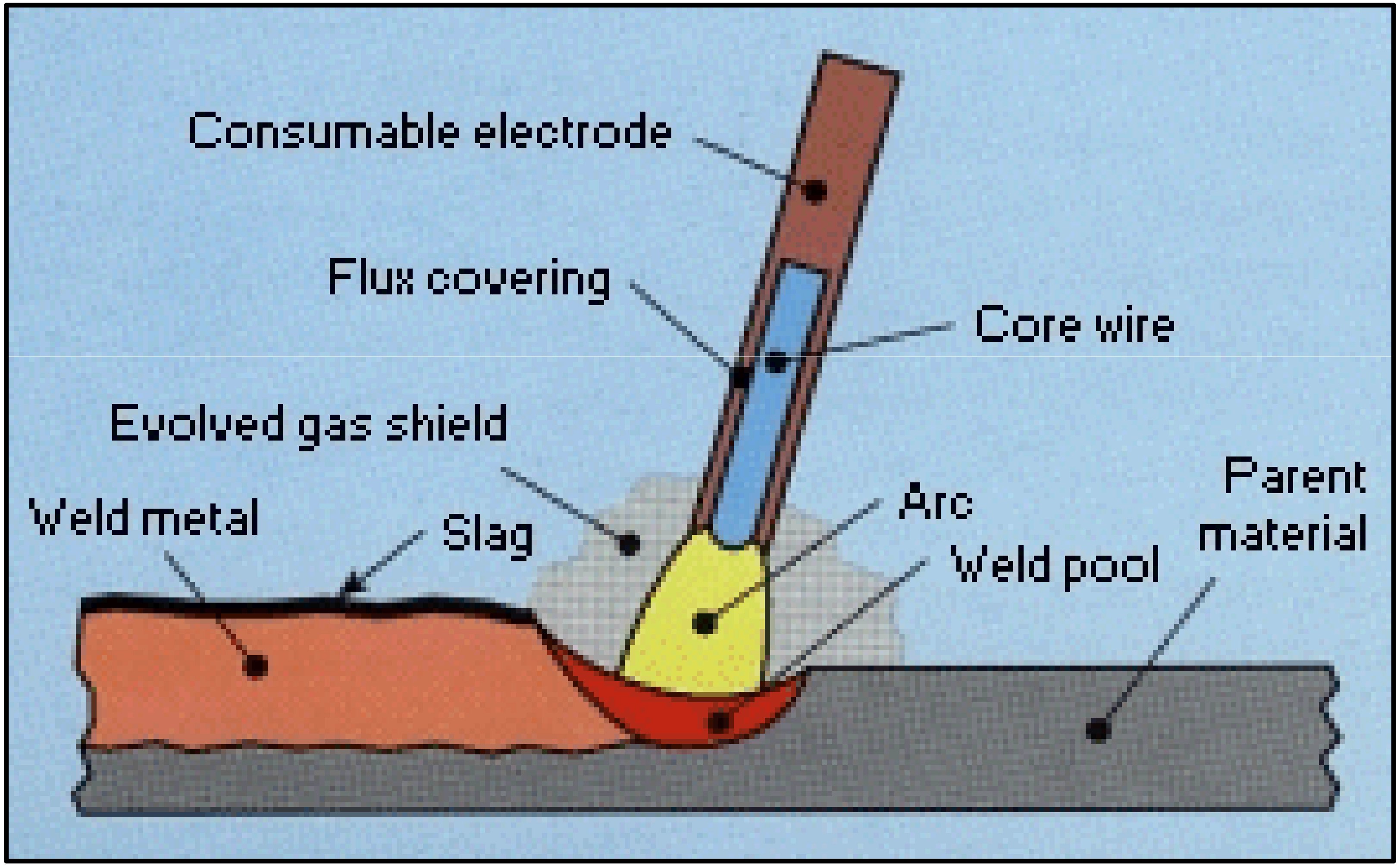
(iv) Submerged Arc Welding (SAW)

(B) Non Consumable Arc Welding Processes:

(v) Gas Tungsten Arc Welding (GTAW)

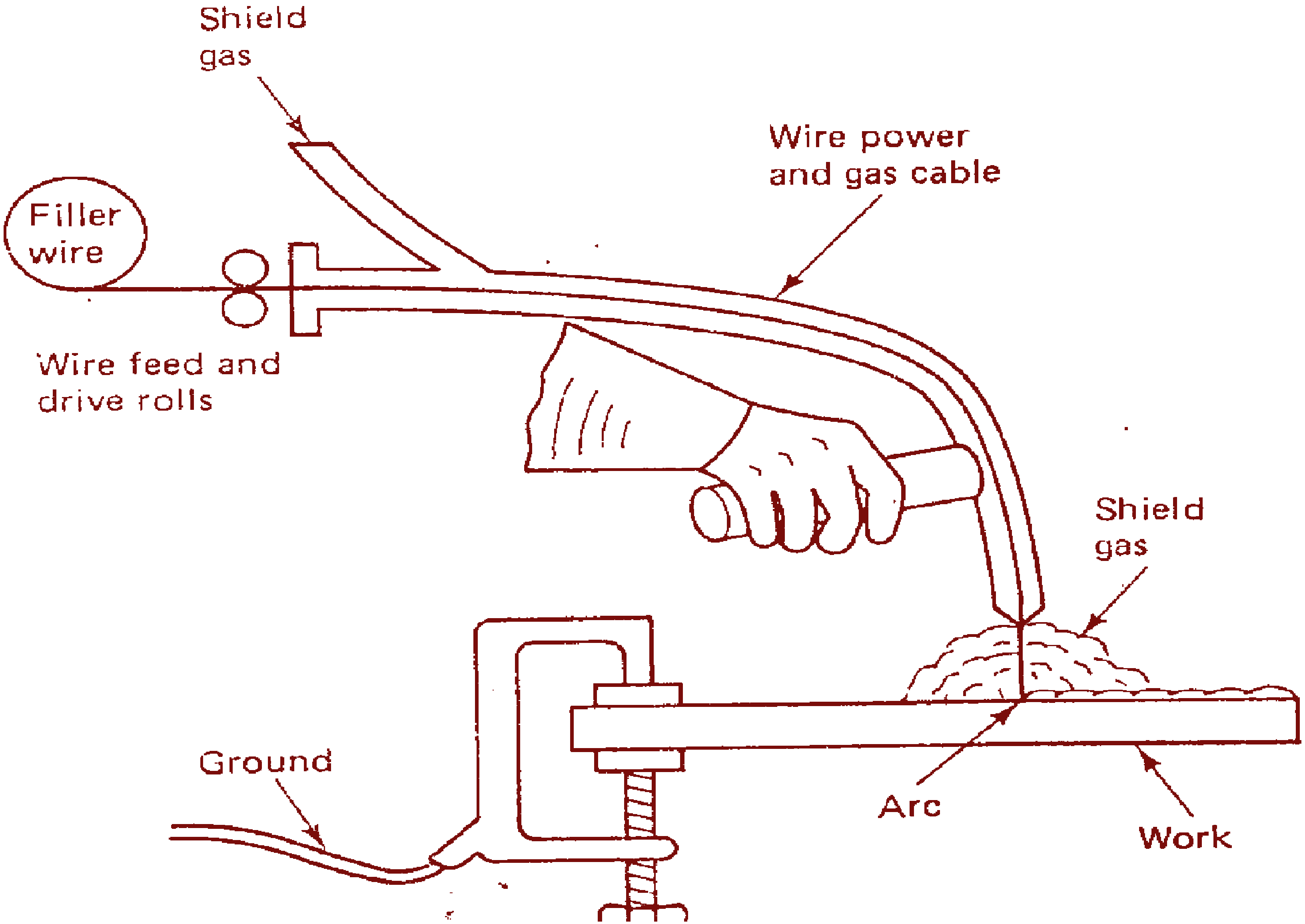
(vi) Plasma Transferred Arc Welding (PTAW)

Shielded Metal Arc Welding (SMAW)

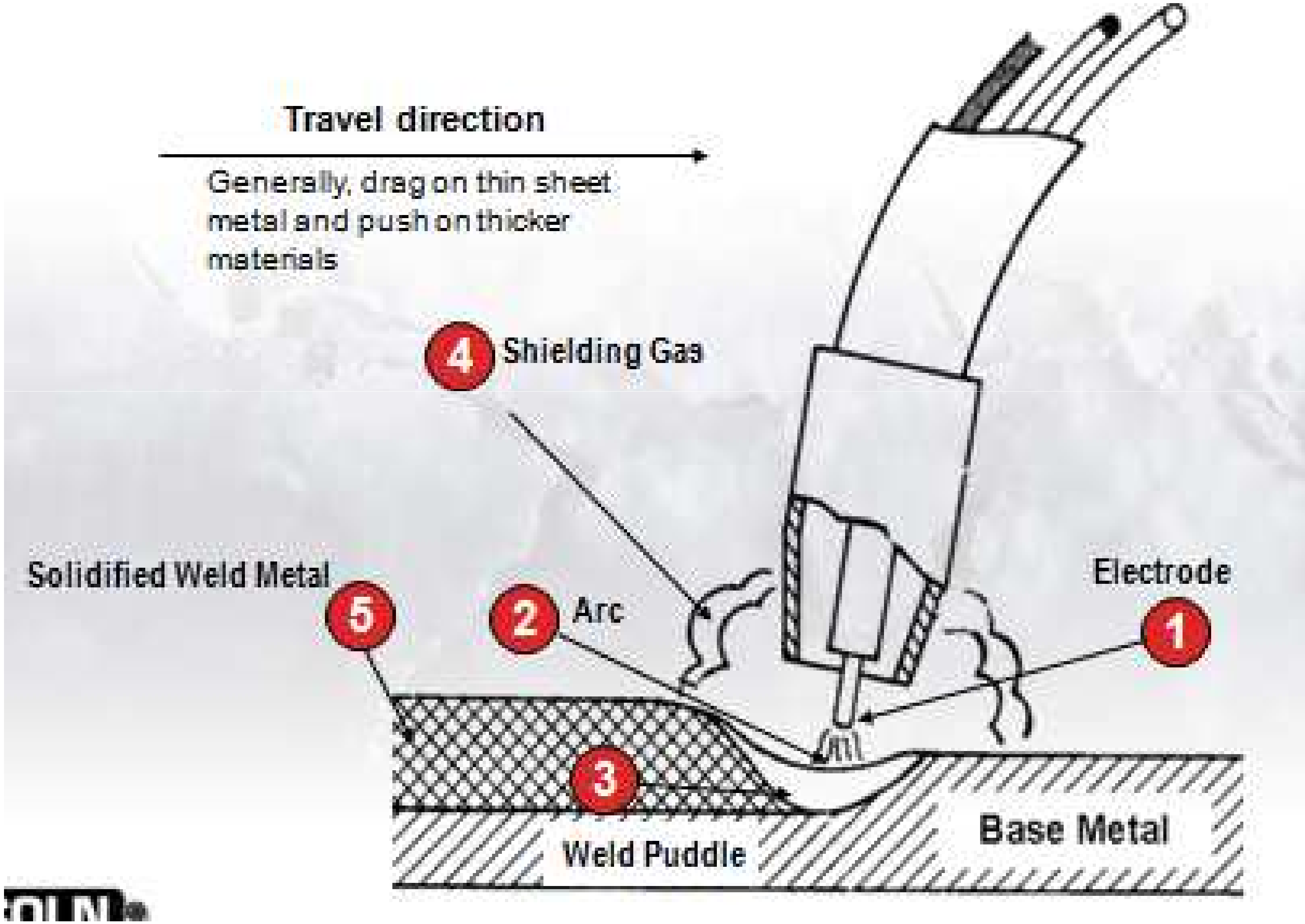


SMAW

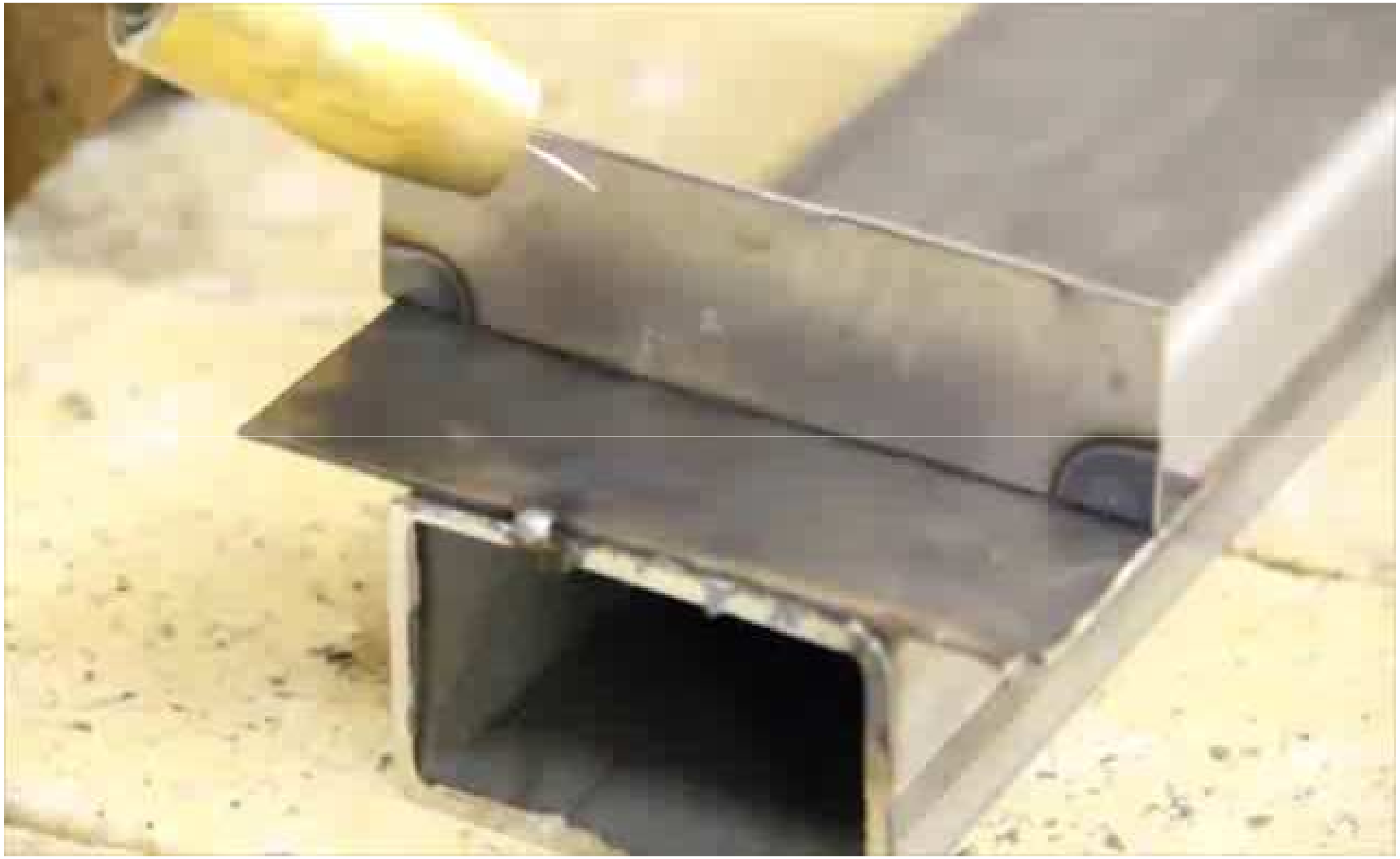
GAS METAL ARC WELDING (GMAW)



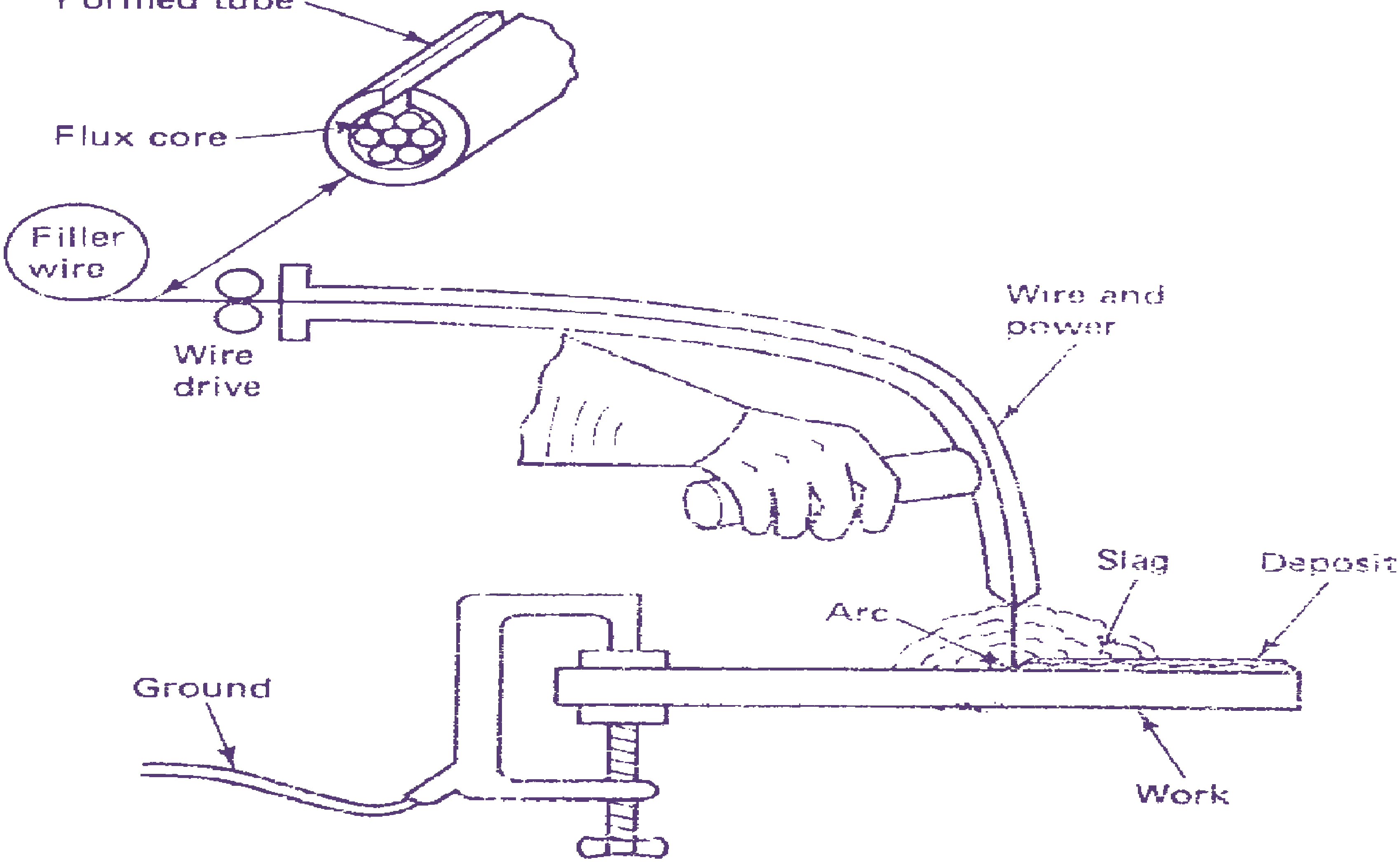
GMAW TORCH


Travel direction
Generally, drag on thin sheet metal and push on thicker materials
4 Shielding Gas
Solidified Weld Metal
5
2 Arc
Electrode
1
3
Weld Puddle
Base Metal

GMAW

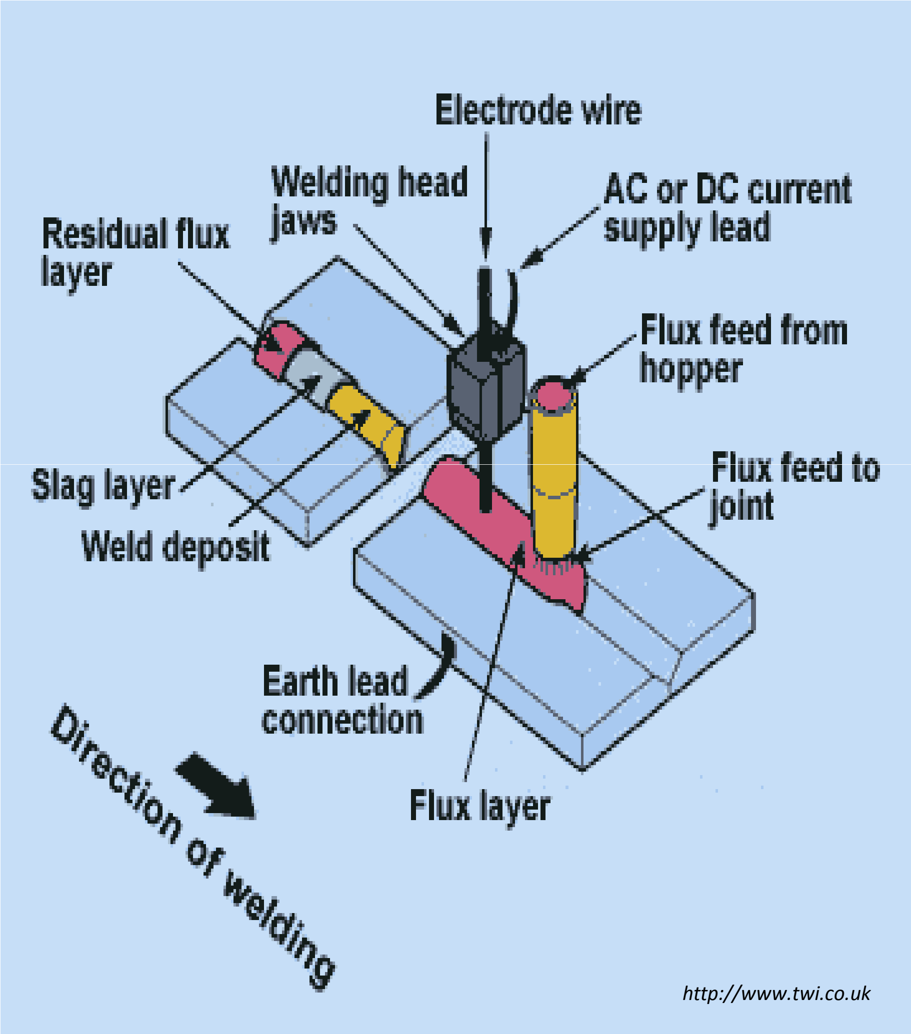


FLUX CORED ARC WELDING (FCAW)



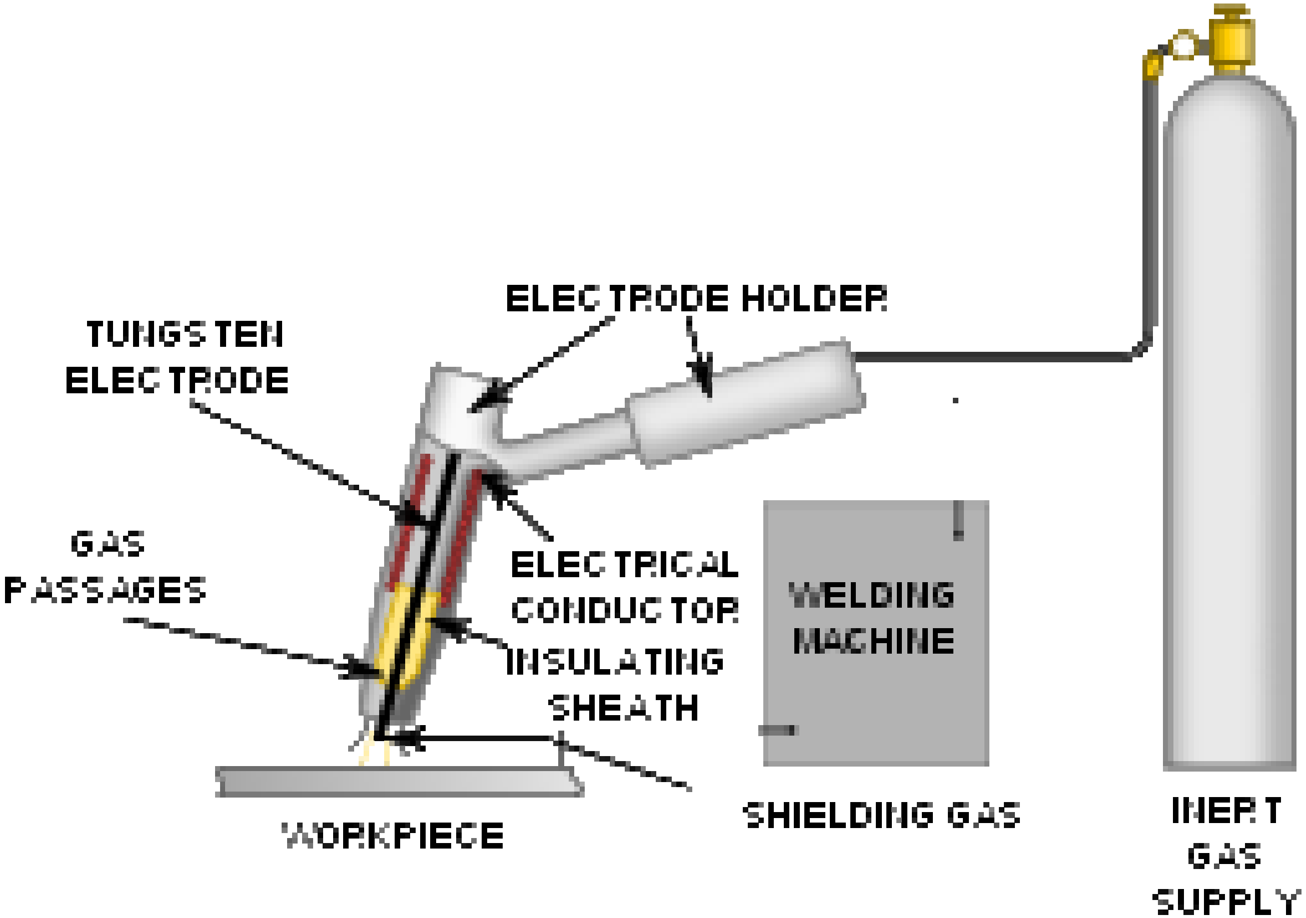
FCAW

SUBMERGED ARC WELDING

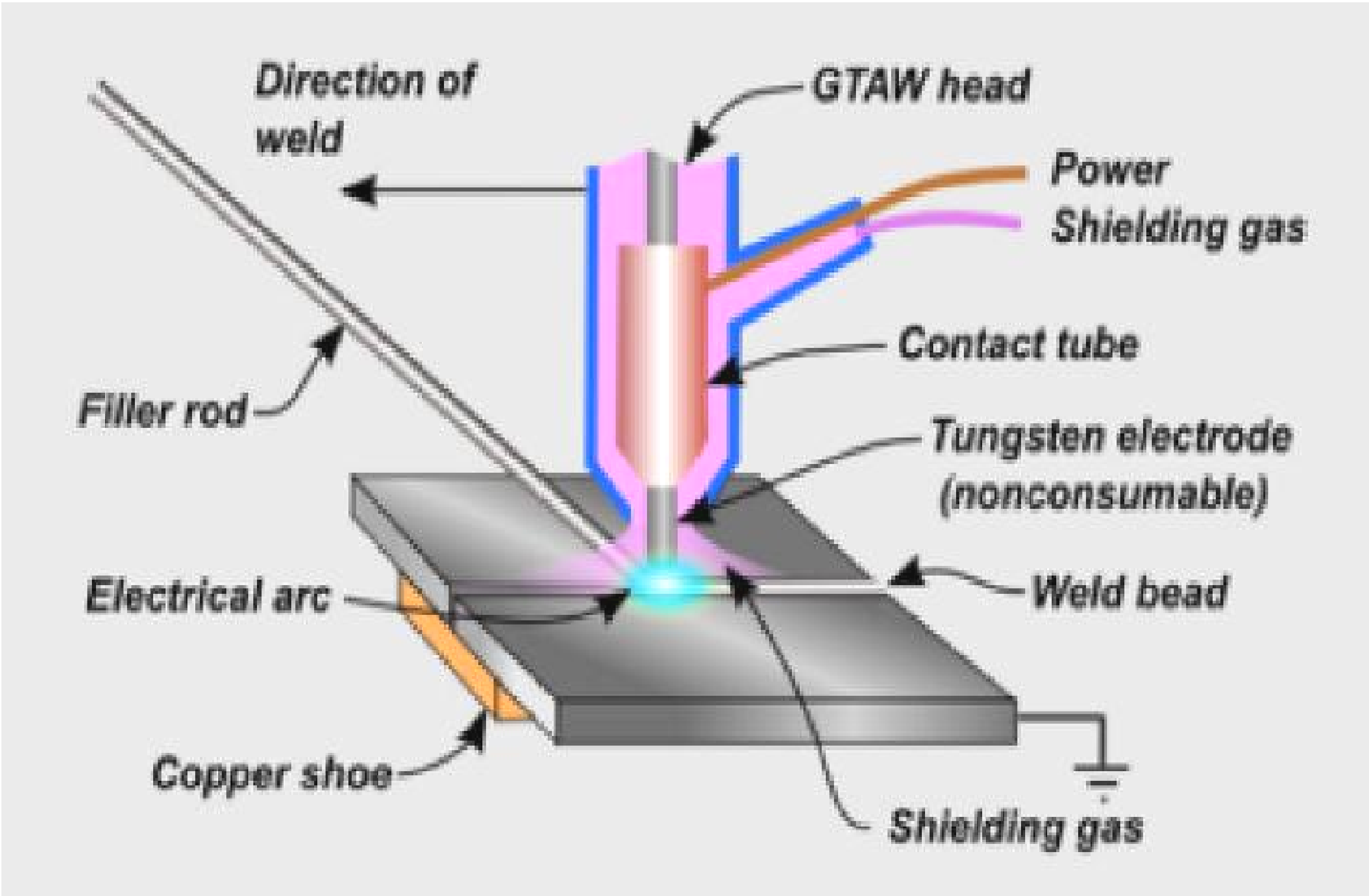


SAW

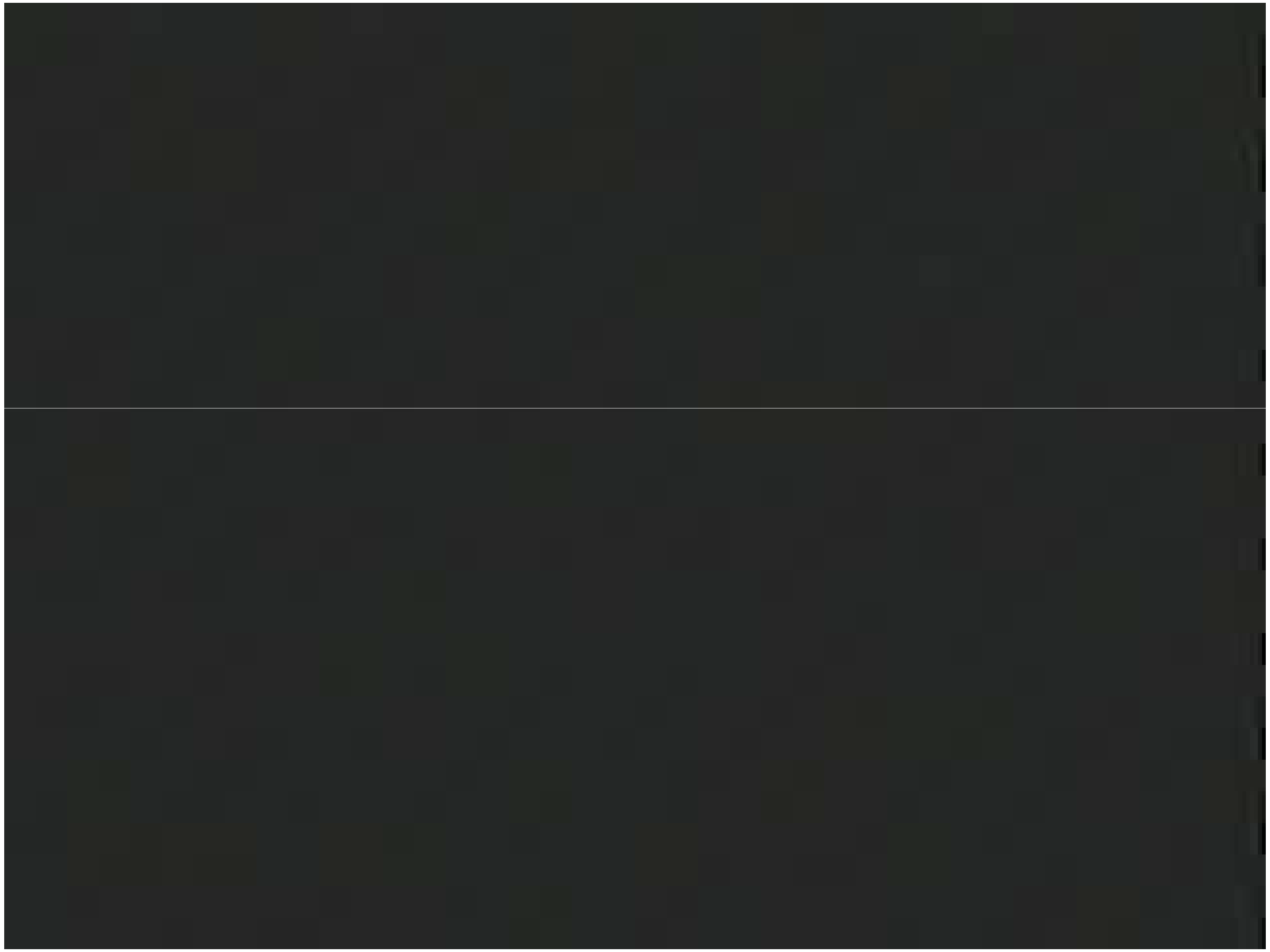
GTAW SETUP


ELECTRODE HOLDER
TUNGSTEN
ELECTRODE
GAS
PASSAGES
ELECTRICAL
CONDUCTOR
INSULATING
SHEATH
WELDING
MACHINE
WORKPIECE
SHIELDING GAS
INERT
GAS
SUPPLY

Gas Tungsten Arc Welding (GTAW)

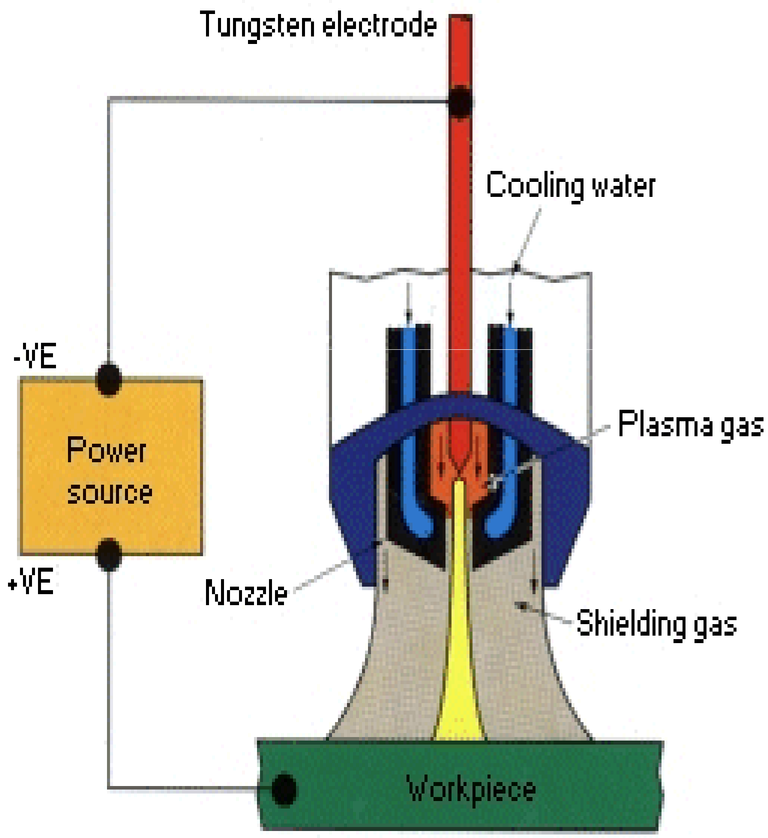


GTAW



PLASMAS ARC WELDING (PAW) PROCESS

- Generally operated on DC with a drooping characteristic power source.
- A plasma control console can be added to a TIG power source
- A pilot arc is first struck between the electrode and copper nozzle and then main arc struck with the work-piece when welding.
- A HF unit is required only at the start to strike the pilot arc.
- The plasma gas is generally Argon or sometimes Argon-Helium and the shielding gas Argon + 2-5% H2.
- The electrode is Tungsten + 2% Th



PAW


MELT TOOLS
http://www.melttools.com
Keyhole pass
NDA
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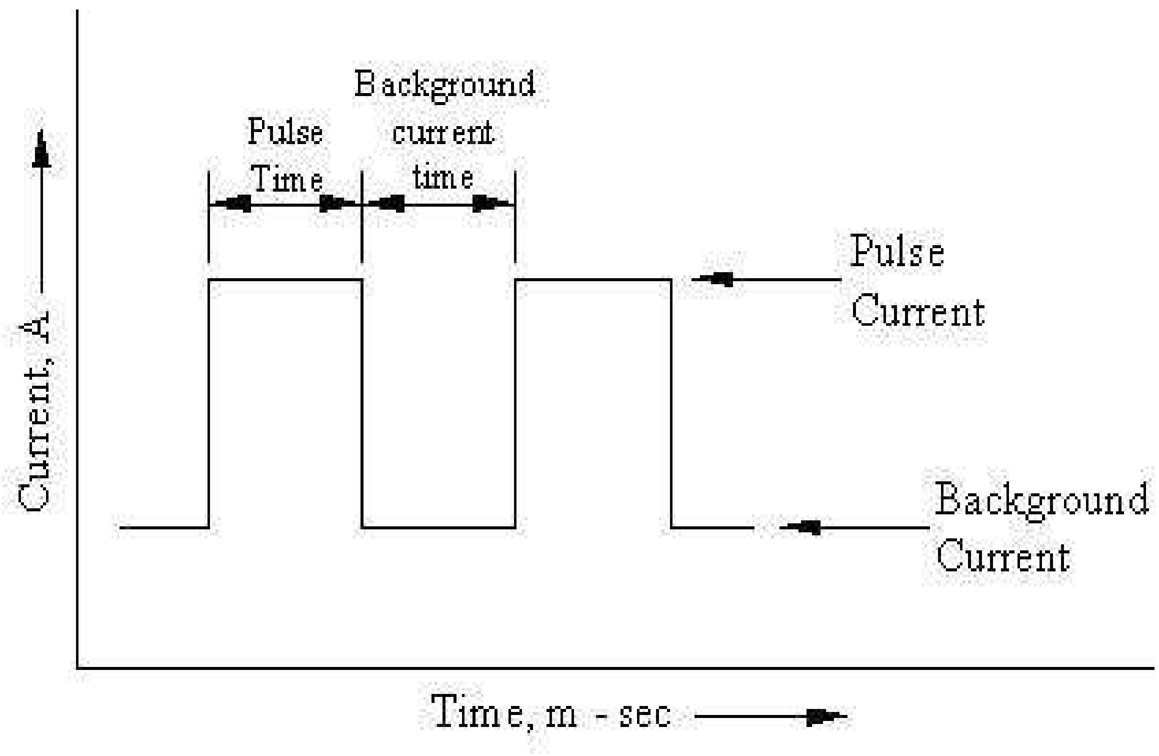
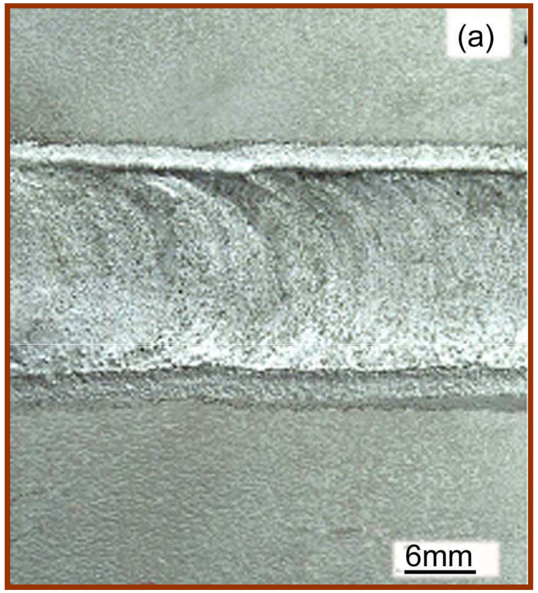
PULSED CURRENT WELDING



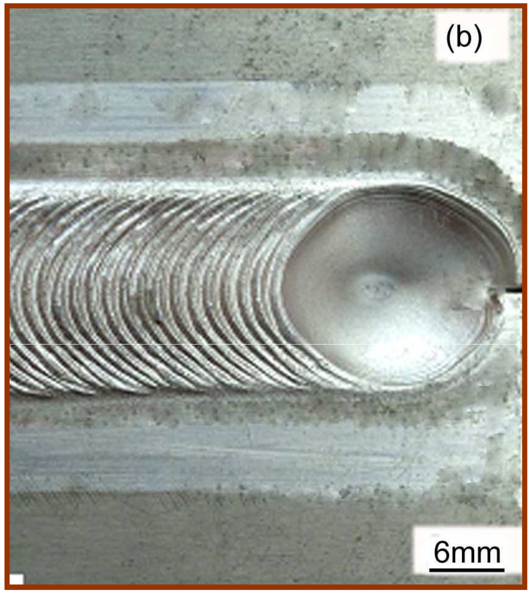
- **Peak Current is used to melt the electrode and detatch the molten droplet**
- **Base current is used to maintain the arc**
- **Between pulses heat will dissipate and gives cushioning effect**
- **Pulsed current produces fine equiaxed grains**
- **Stress relaxation takes place**
- **This technique is good for hot cracking susceptible materials**

How Pulsed TIG welding Works?

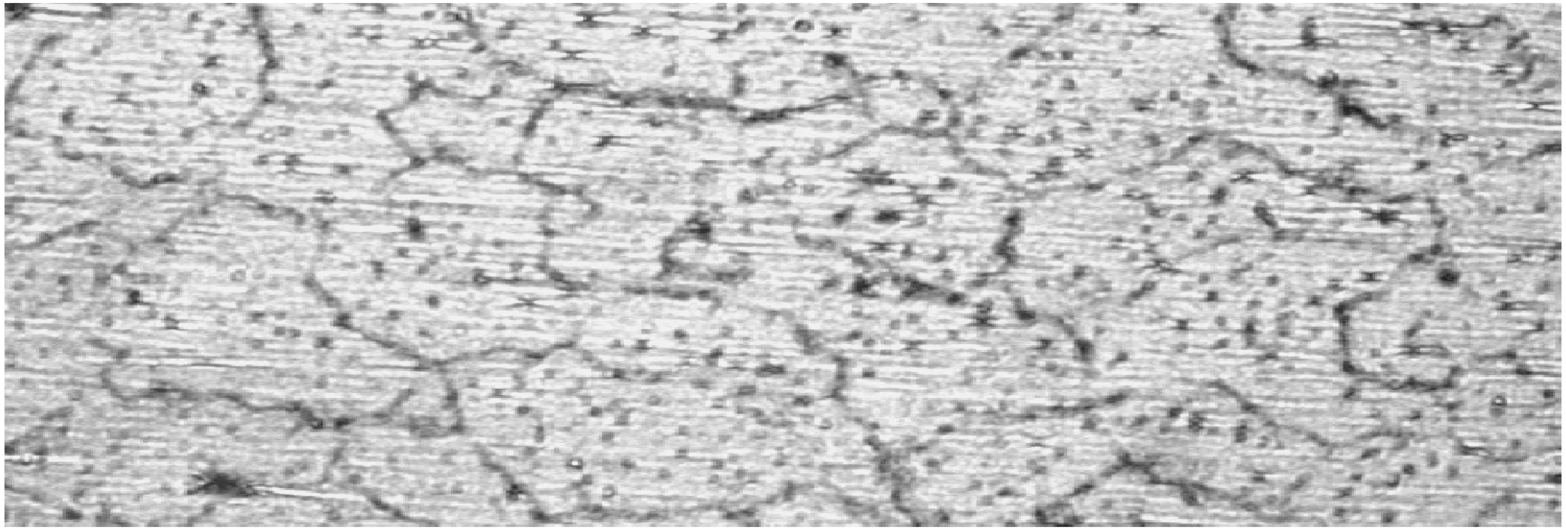
BEAD SHAPE



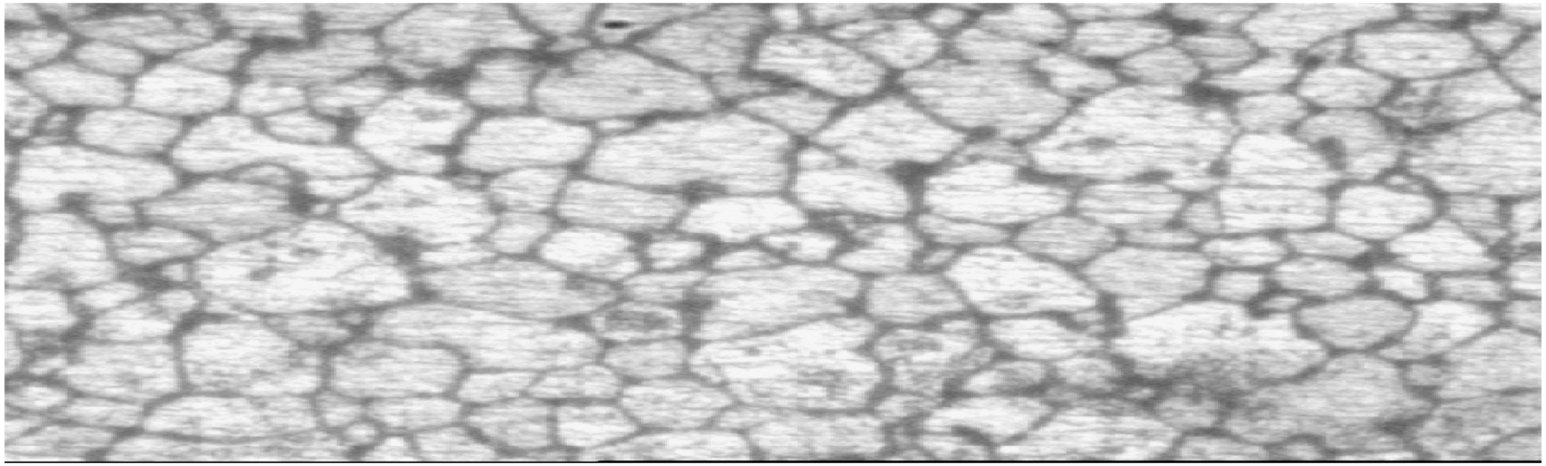
Constant Current GTA weld



Pulsed Current GTA weld



a) CCTIG

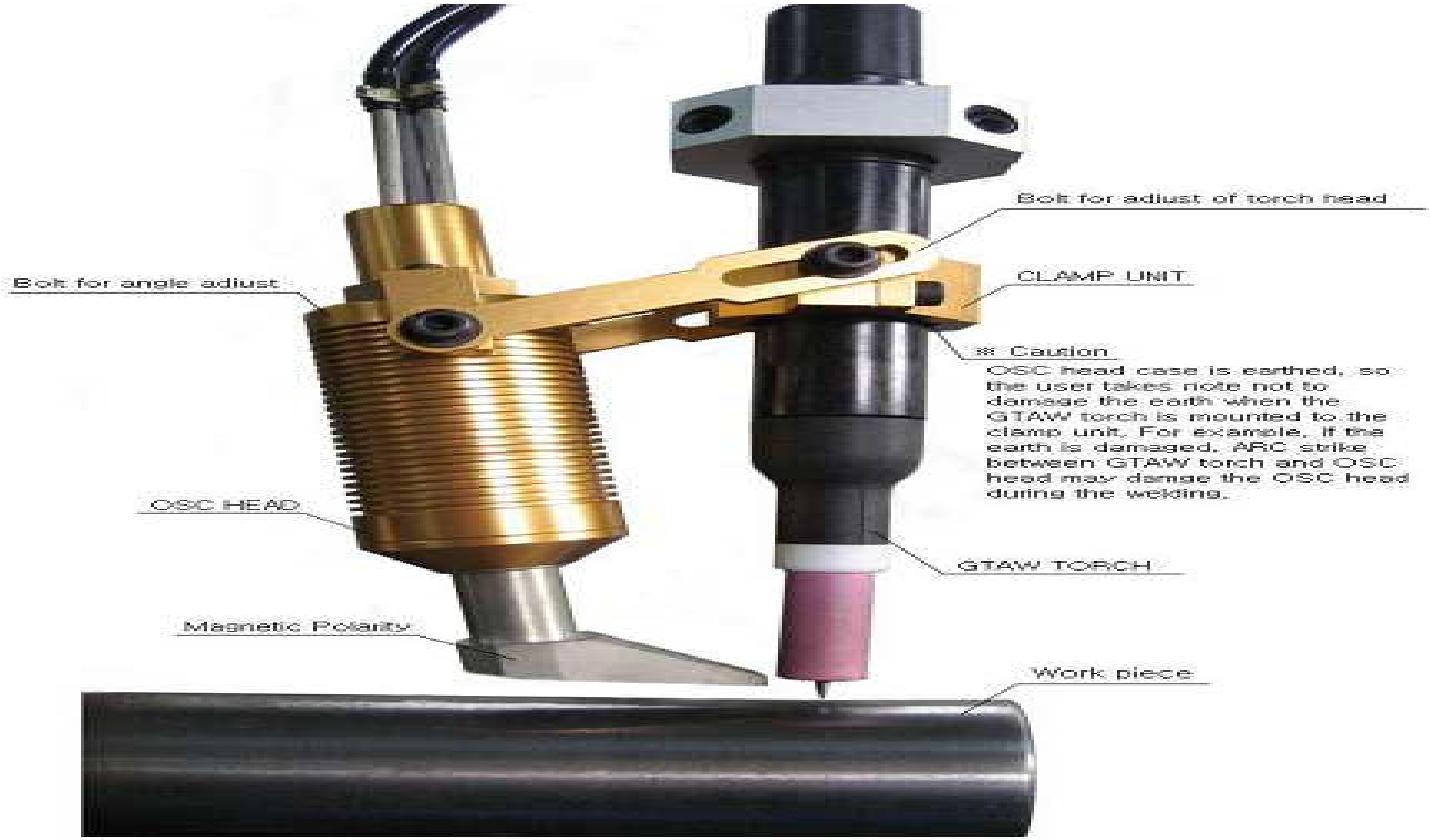


b) PCTIG

MAGNETIC ARC OSCILLATION (MAO)

- ARC IS OSCILLATED BY MEANS OF EXTERNAL MAGNETIC FIELD
- SURROUNDING THE ARC 4 OR 8 PERMANENT MAGNETS ARE ARRANGED
- EACH MAGNETS ARE SEQUENTIALLY ENERGISED
- MAKES THE ARC TO ROTATE
- WELD POOL EXPERIENCES STIRRING ACTION
- GRAIN REFINEMENT TAKES PLACE

Magnetic Arc Oscillation Setup



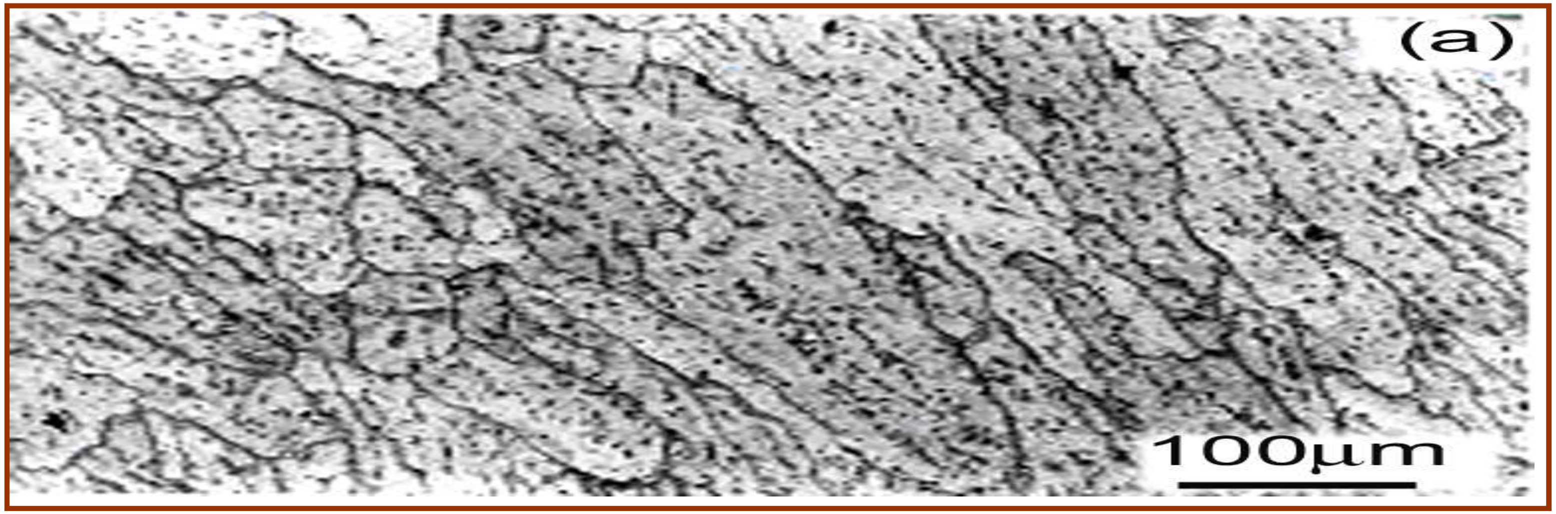
Magnetic Head Unit

- Inside the head there is the coil winded for production of the electromagnetic force.

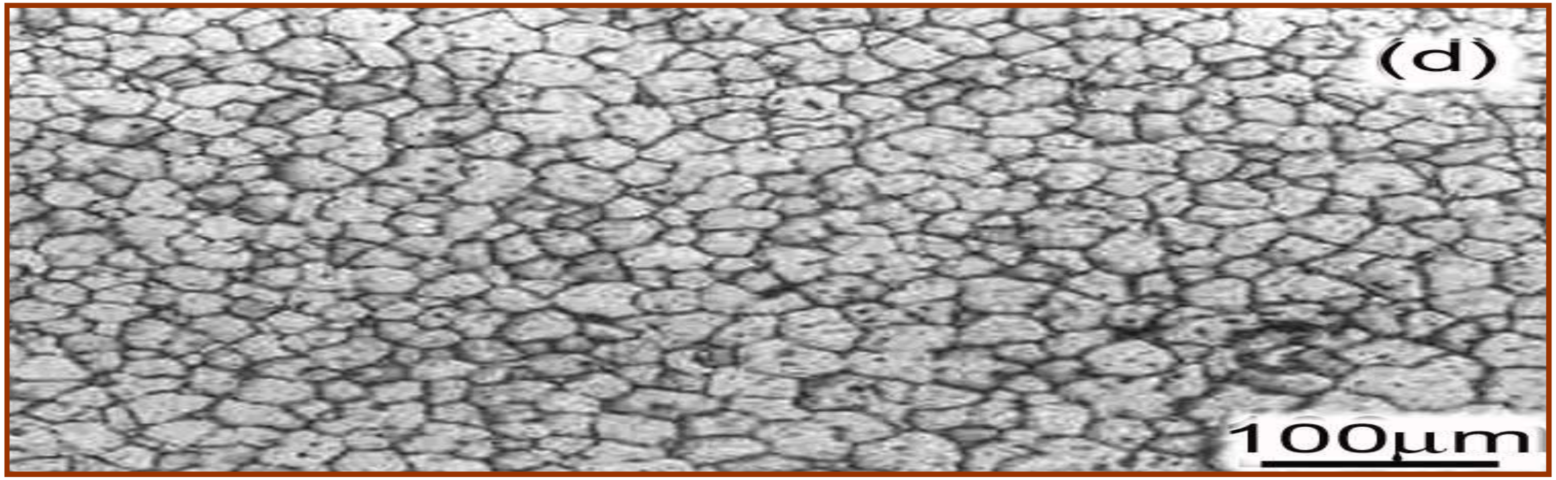
- The pole of the head is mounted near the ARC so the head should be protected from the heat by using the water cooling.


1427
MAGNETIC ARC
OSCILLATOR

WELD METAL MICROSTRUCTURE

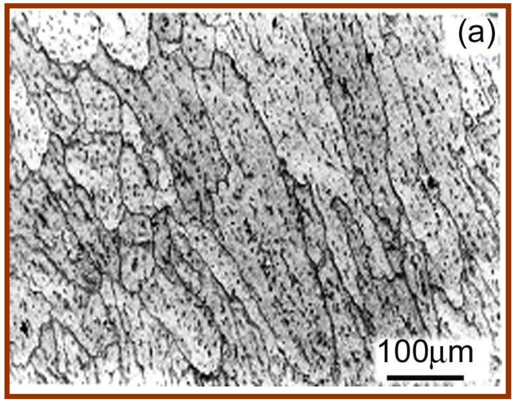


WITHOUT ARC OSCILLATION

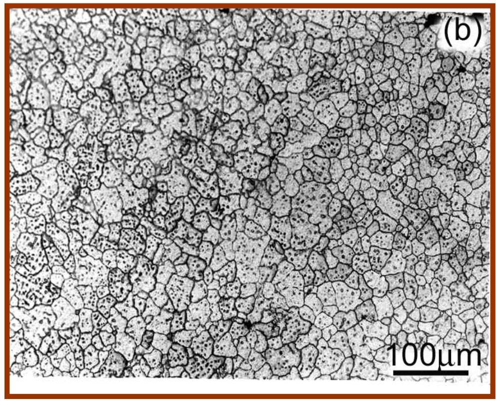


WITH ARC OSCILLATION

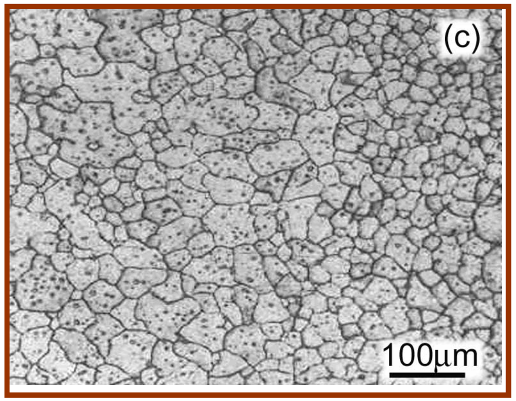
WELD METAL MICROSTRUCTURE



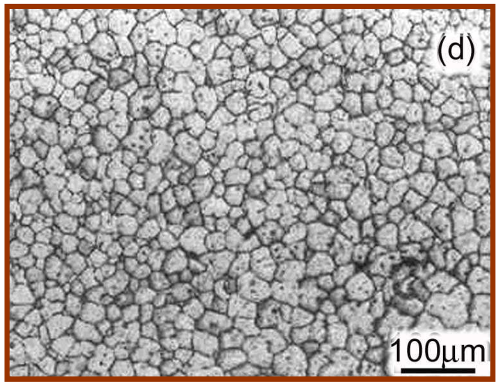
CC



PC



AO



PCAO

BENEFITS OF PC AND MAO

- FINE GRAINS IN THE WELD FUSION REGION
- MECHANICAL PROPERTIES SUCH AS TENSILE, IMPACT AND FATIGUE HAVE BEEN ENHANCED
- REDUCES THE HOT CRACKING PROBLES

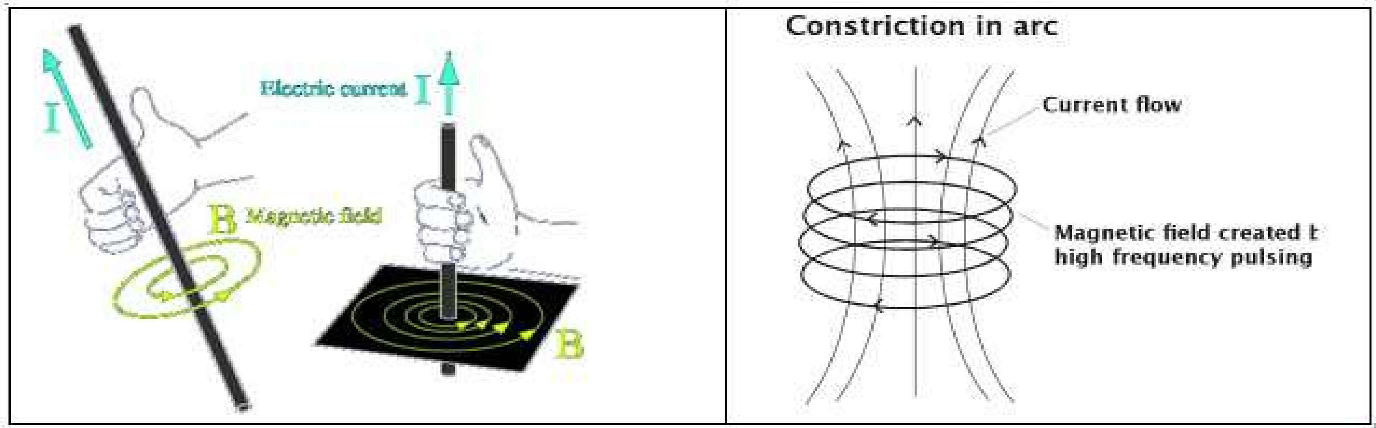
GAS TUNGSTEN CONSTRICTED ARC WELDING (GTCAW)

- The Gas Tungsten Constricted Arc (GTCAW) process is an advanced modification of conventional GTAW process.
- It is popularly known as Interpulse TIG Welding process.
- Using magnetic constriction and high frequency (20,000Hz) modulation of the arc waveform to produce a constricted arc
- Greatly reduces the overall heat input during welding.

Principle of GTCAW Process

❑ Right Hand Rule

❖ The right hand rule is useful for visualizing the direction of a magnetic force as given by the Lorentz force law. The force is in the opposite direction for a negative charge moving in the direction shown.



❑ Arc Constriction

- The welding arc is constricted by the magnetic field around the arc. The InterPulse machine generates high frequency pulse, the relationships of which are programmable to alter the magnetic field of the arc, thus enabling the control of the constriction of the arc.

IPTIG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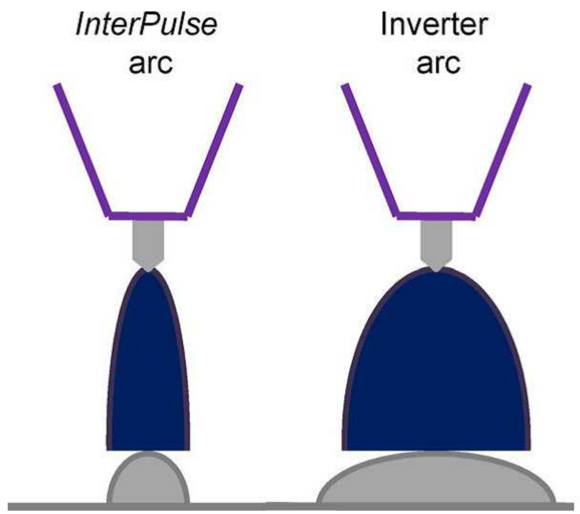
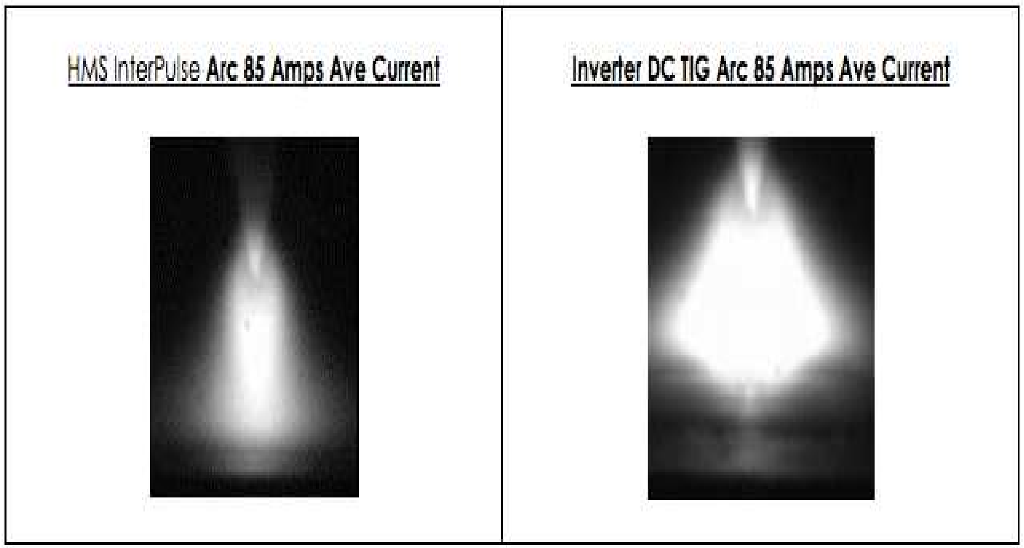
IPTIG ARC CHARACTERISTICS

- The superposition of the high frequency (20,000 Hz) waveform on the main current leads to a narrower and stiffer arc than conventional inverter GTAW.

- Precise arc width is 2 mm and the arc remains constant even well below 0.5 amp.





Salient features

	LASER / PAW	INTERPULSE TIG
Metallurgical Quality	Porosity may be present	X-Ray Quality
Part Protection	Masking required due to spatter	Not required
Filler Metal Feed control	Not adjustable during welding	Precision control
Running cost	High	Low comparatively
Flexibility	Difficult to maneuver due to torch size	Acceptable
Process Repeatability	Power feed rate and deposition difficult to control	Electrode needs to be sharpened or changed
Process Adaptability	Difficult to weld with filler due to small focus beam	Easy to use
Environmental Safety	Human Hazard unavoidable	Low risk

Applications

- **Welding of similar nickel-based superalloys such as Inconel and Titanium alloys.**

- **Welding of dissimilar super alloys**

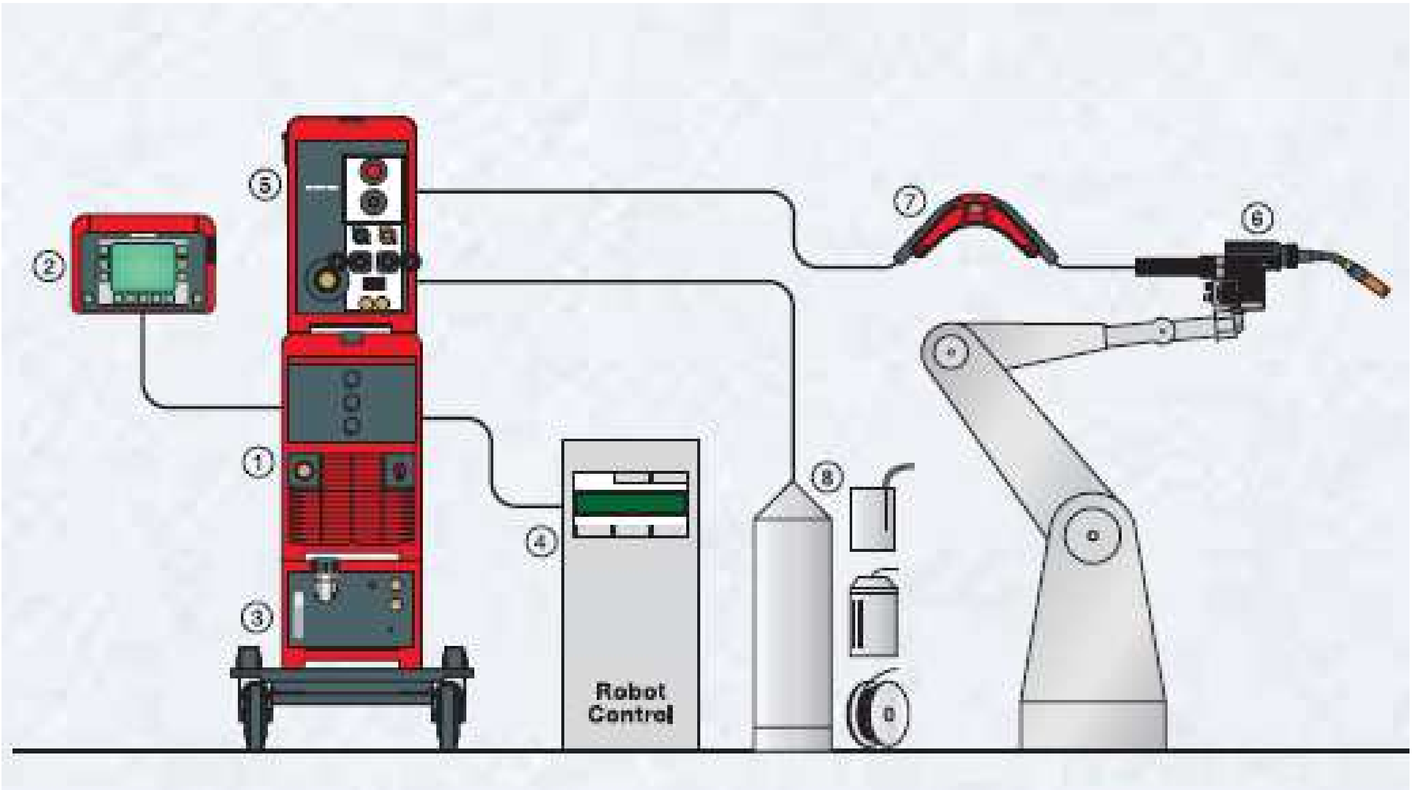
- **Repair of aero engine materials**

Advantages of IPTIG

- Narrow weld width
- Reduced HAZ
- Up to 30% less heat input
- Non requirement of trailing gas shield
- Out of chamber welding

COLD METAL TRNASFER (CMT) PROCESS

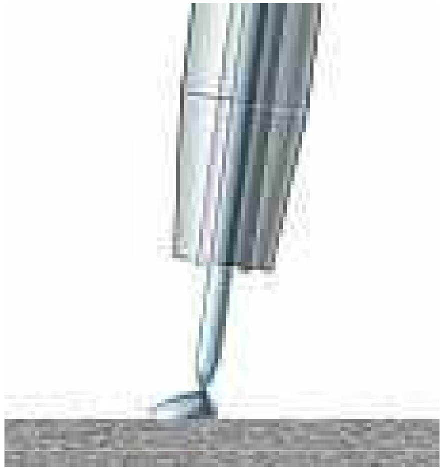
- **Dip arc process with completely new method of droplet detachment**
- **Metal transfer relatively cold (low temp) compared with conventional GMA process**



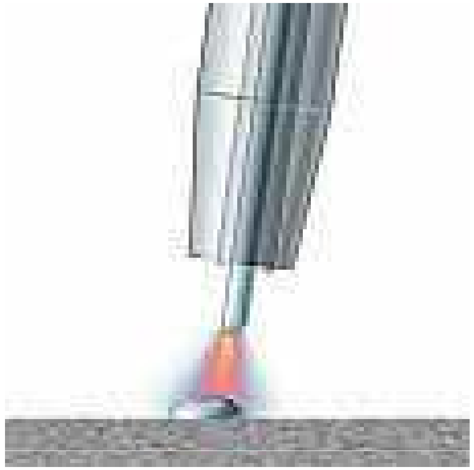
CMT : Principle

1. During the arcing period, the filler metal is moved towards the weld-pool.

2. When the filler metal dips into the weld-pool, the arc is extinguished. welding current is lowered.



3. The rearward movement of the wire assists droplet detachment during the short circuit.



4. The wire motion is reversed and the process begins all over again.

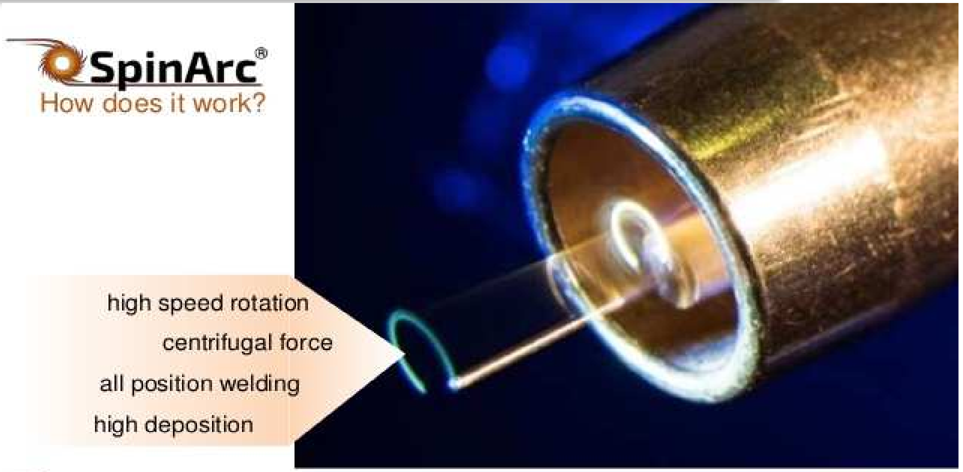
How Does CMT Works?

WHY CMT WELDING PROCESS ?

- It is a Low Current and Low Voltage process
- Hence it is a Low heat input process
- Peak temperature is low due to low heat input
- Fast Cooling Rate due to low Peak temperature
- Formation of intermetallics is minimum due to above reasons.
- Narrow heat affected zone due to low heat input
- Fast process and hence productivity is higher
- Best suited for thin sheet welding
- Spatter free process
- Less Pollutant compared to conventional GMAW process

SPIN ARC WELDING

- ❖With Spin Arc, welding out of position is possible and provides high-quality welds with very high Productivity.
- ❖Also, the weld joint can be modified so the need for beveling is reduced or eliminated.
- ❖The stirring action of the arc in the weld pool results in cleaner welds with enhanced properties.
- ❖With the Spin Arc system, the arc flattens the puddle, spreading out the energy. The resulting flat weld is better for a variety of applications



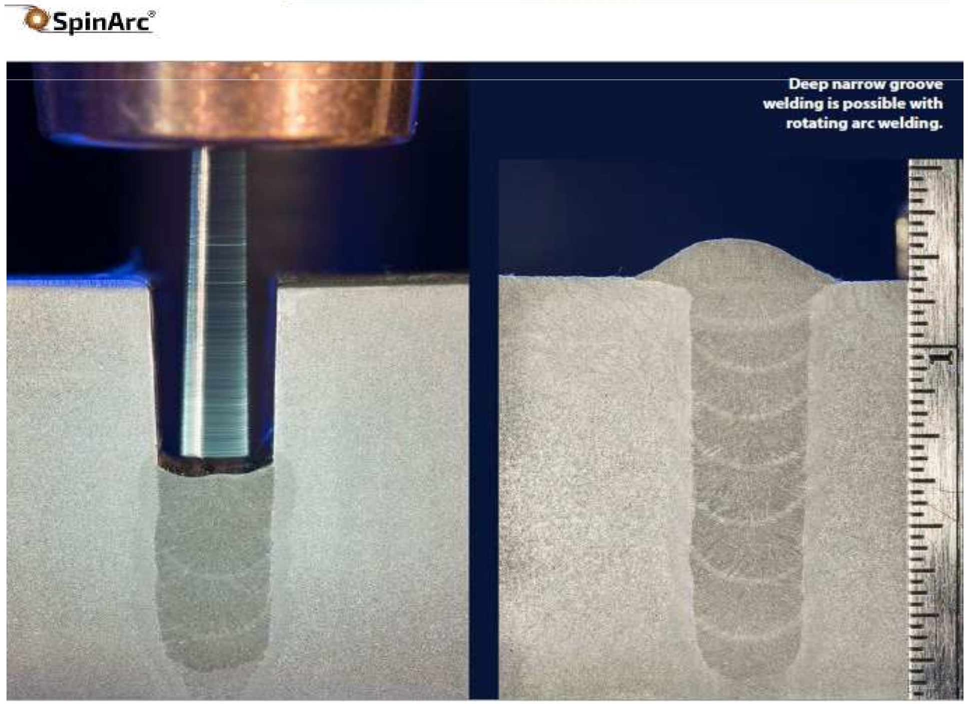
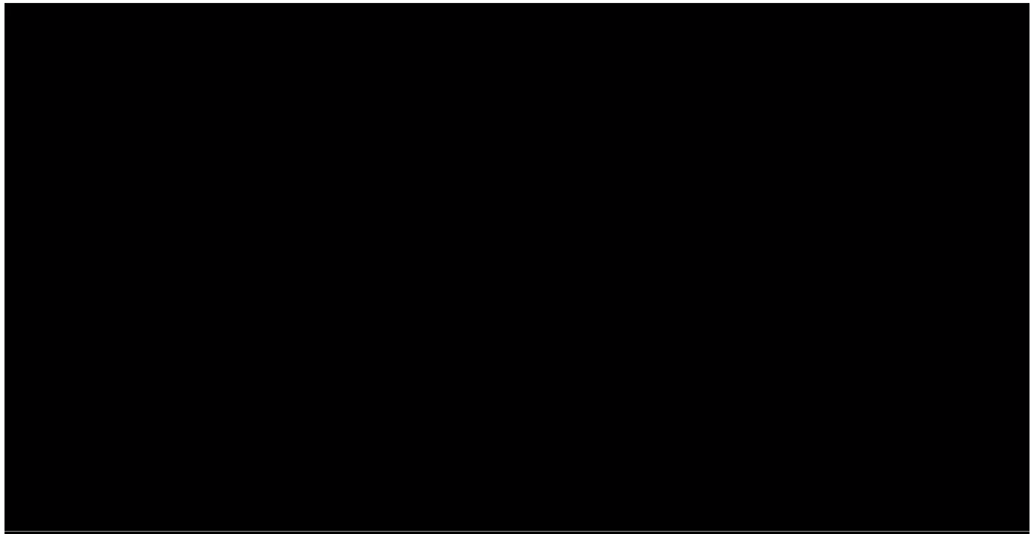
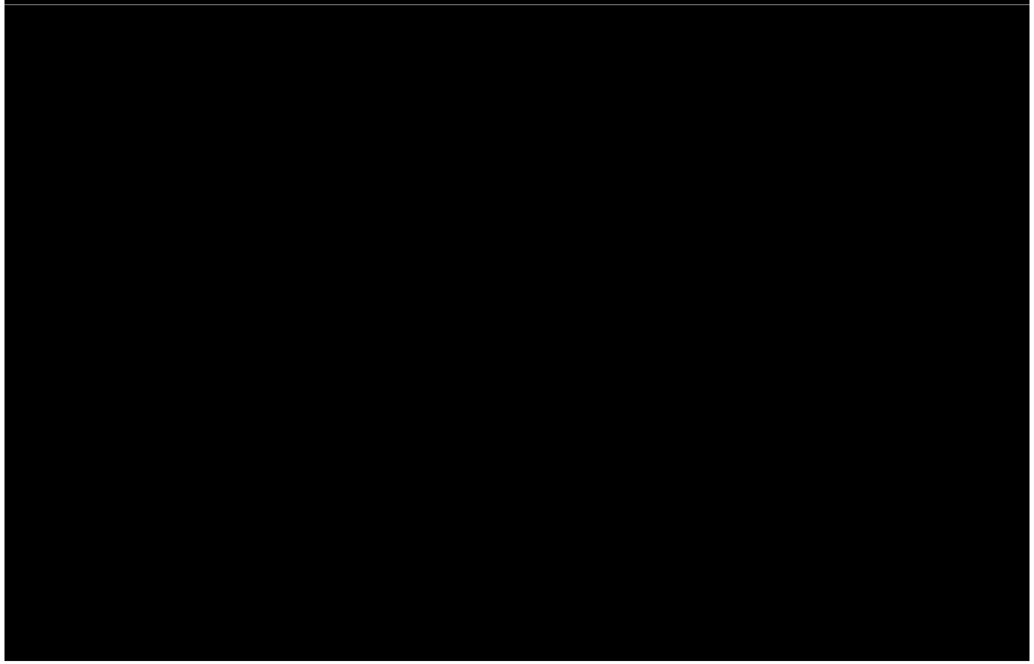


Fig. The rotating arc welding torch

Working Principle of SPIN ARC

- The welding electrode rotates in a circular motion at a high rate of speed.
- During welding, the molten droplets are propelled from the wire to the base metal in a circular pattern.
- The rotation it self spreads the arc energy out and provides a very consistent penetration and bead profile for the weld.
- Rotating arc welding is that the high speed rotation enables productivity gains in a variety of applications

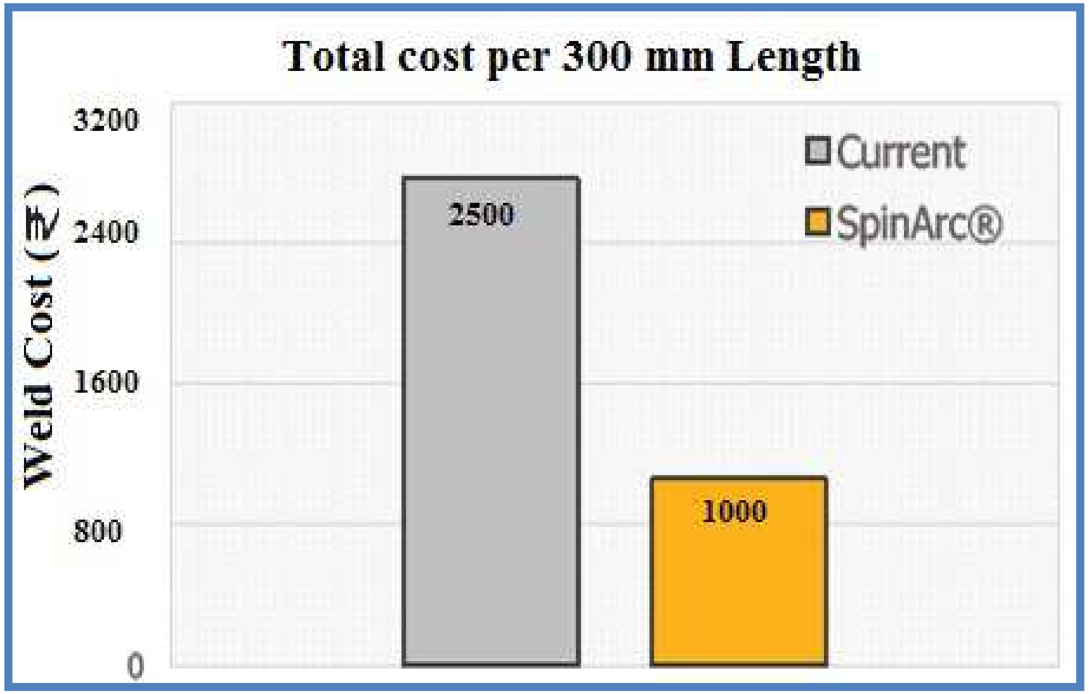




ADVANTAGES OF SPIN ARC WELDING

Why choose Spin Arc?

- ✓60% Productivity increase
- ✓40% Weld cost reduction
- ✓60% Less weld metal
- ✓Reduced distortion
- ✓No slag removal
- ✓No beveling



Conventional GMAW Joint Design **Spin Arc GMAW Joint**

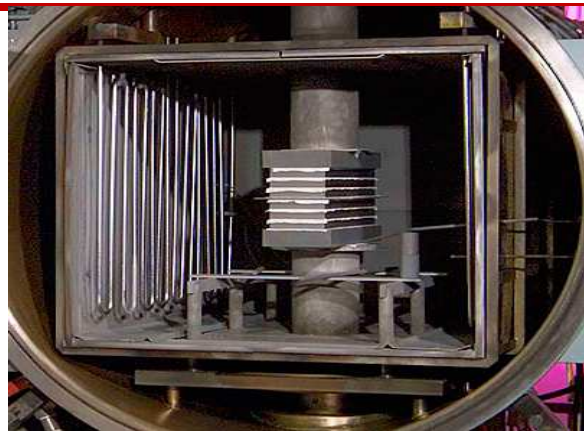
PHASE 2:

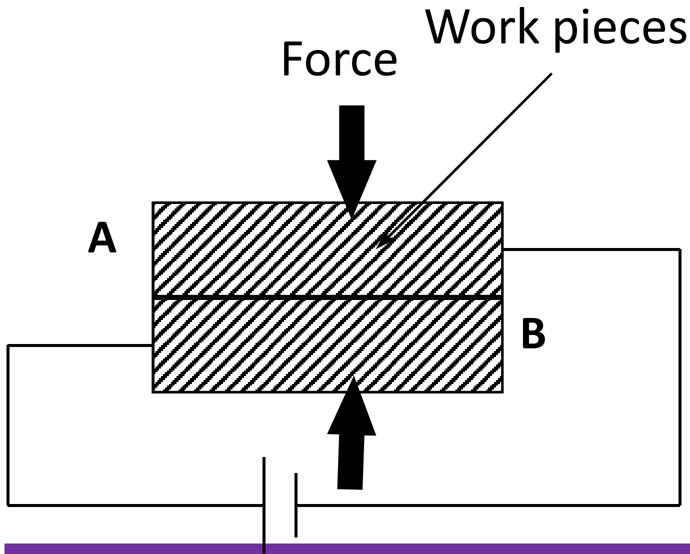
SOLID STATE WELDING PROCESSES

DIFFUSION BONDING

DEFINITION OF DIFFUSION WELDING

- A **solid-state welding** process that produces coalescence of the faying surfaces by the **application of pressure at elevated temperature**.
- The process **does not involve macroscopic deformation**, or relative motion of the workpieces.
- A solid **filler metal may or may not be inserted** between the faying surfaces.





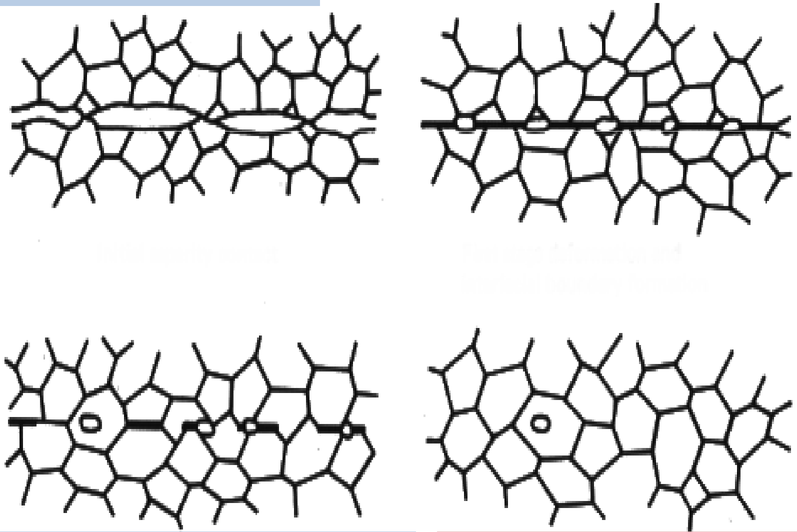
Schematic representation of diffusion welding

DIFFUSION WELDING WORKING PRINCIPLES

- 1st stage
  - deformation forming interfacial boundary.
- 2nd stage
  - Grain boundary migration and pore elimination.
- 3rd stage
  - Volume diffusion and pore elimination.

asperities come into contact.

1st stage deformation and interfacial boundary formation



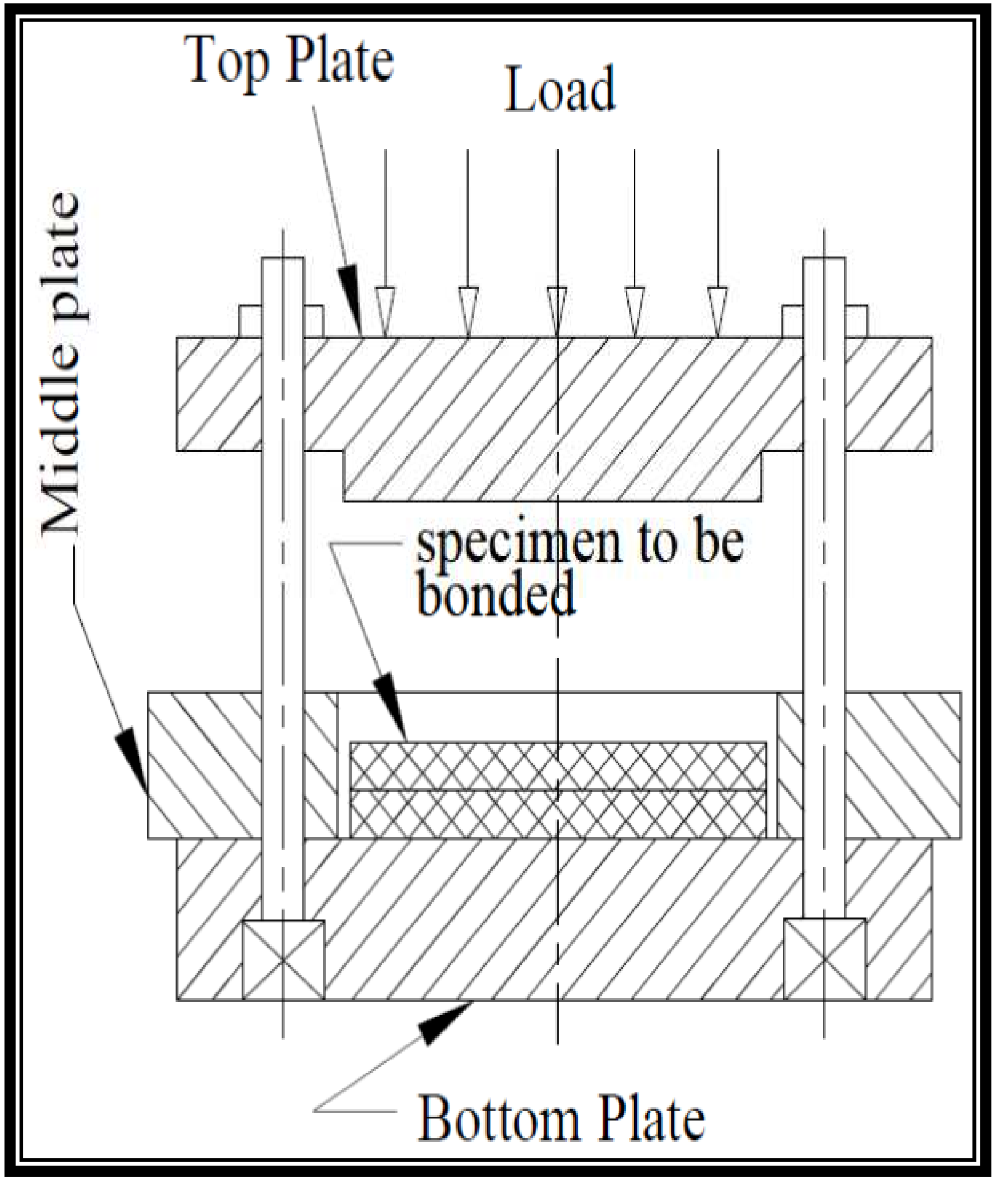
2nd stage grain boundary migration and pore elimination

3rd stage volume diffusion pore elimination

SOLID PHASE DIFFUSION BONDING

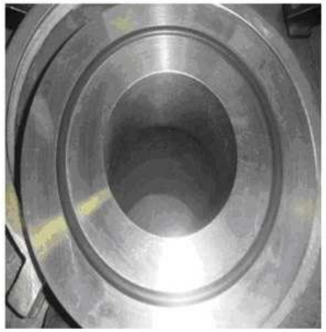
- **Bonding in the solid phase is carried out in vacuum atmosphere**
- **Heat being applied by induction heating**
- **Pressure can be applied uniaxially**
- **The process requires a good surface finish on the mating surfaces**
- **Surface finishes of better than 0.4µm are recommended**
- **Surfaces should be as clean as practical to minimize surface contamination**

DIFFUSION BONDING MACHINE



(a) Diffusion bonding machine

(b) Vacuum furnace



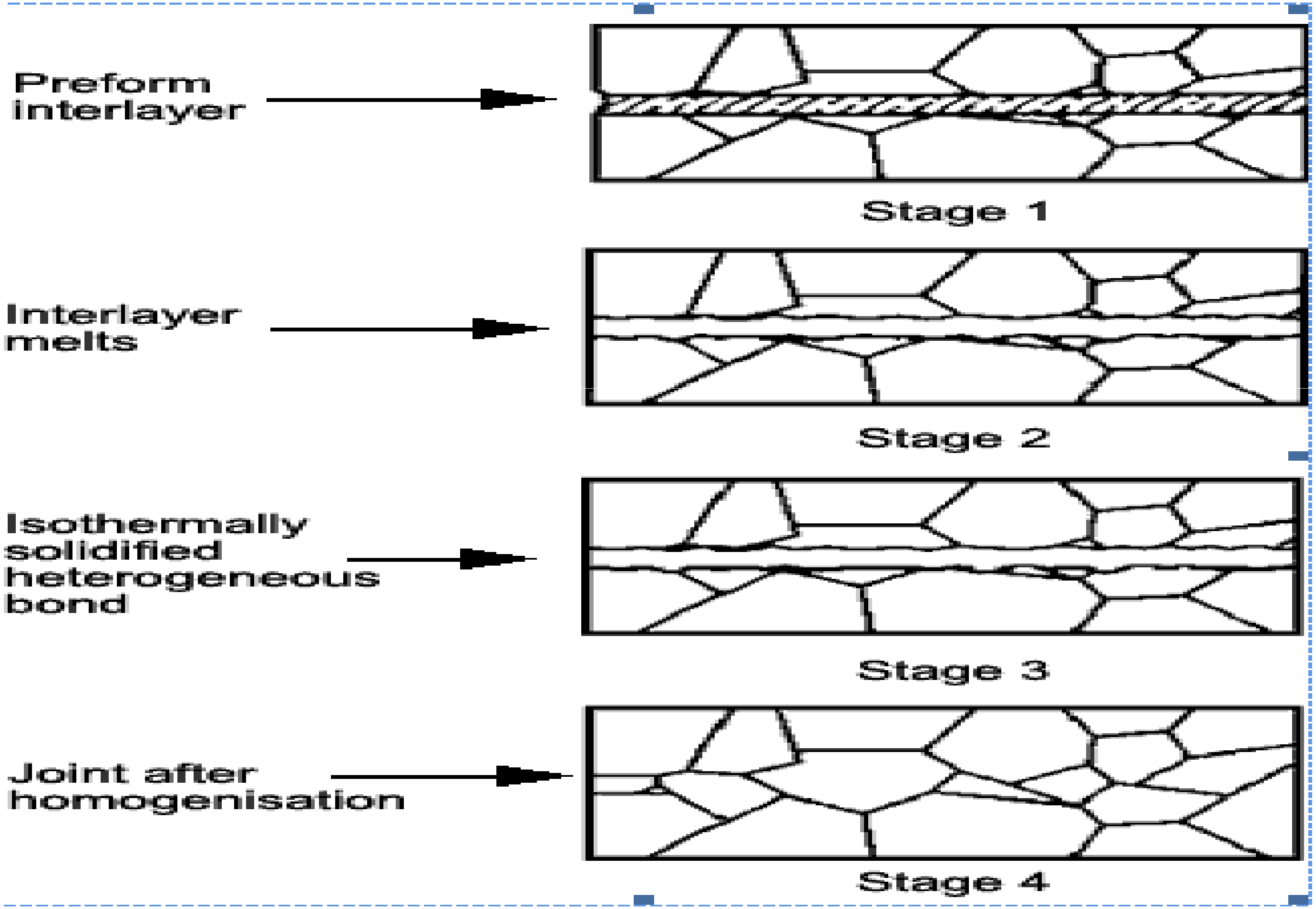
(c) Vacuum chamber

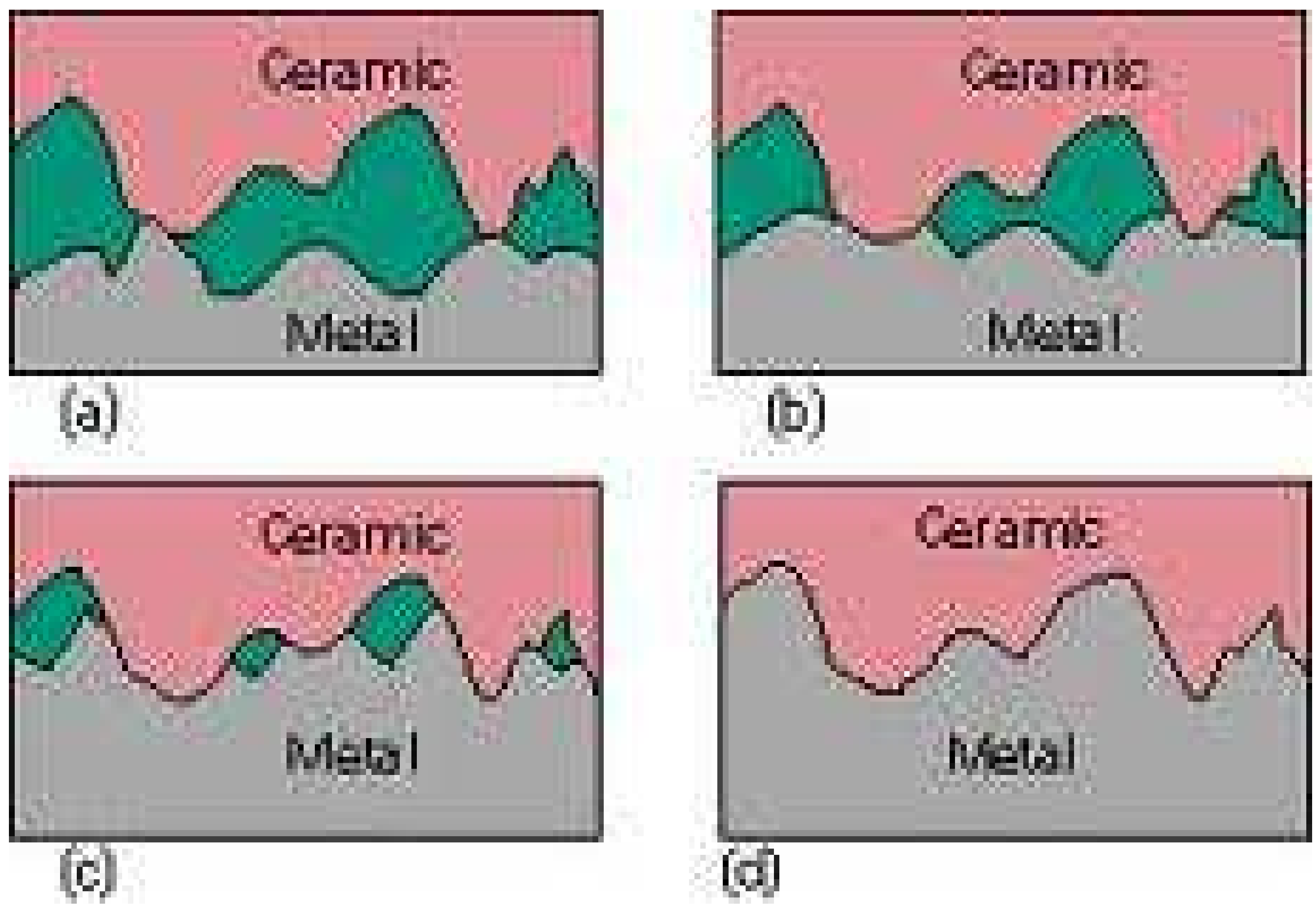
DIFFUSION BONDING : ANIMATION

LIQUID PHASE DIFFUSION BONDING

- **Applicable to dissimilar material combinations, a dissimilar metal insert is used**
- **Solid state diffusion processes lead to a change of composition at the bond interface**
- **The dissimilar metal insert melts at a lower temperature than the parent material**
- **Thin layer of liquid spreads along the interface**
- **To form a joint at a lower temperature than the melting point of the parent materials**

LIQUID PHASE DIFFUSION BONDING




Ceramic
Metal
(a)
Ceramic
Metal
(b)
Ceramic
Metal
(c)
Ceramic
Metal
(d)

WHAT ARE THE CRITERIA TO BE CONSIDERED IN DIFFUSION BONDING

- **SURFACE ROUGHNESS:**

  Surface finishes of better than 0.4 µm are recommended

- **BONDING PRESSURE:**

  The bonding pressure should be high enough to ensure a tight contact between the joining surfaces.

- **BONDING TEMPERATURE:**

  Should be between 50 % and 70 % of the melting point of either of the lowest melting point material.

- **HOLDING TIME:**

  Time is closely related to temperature as most diffusion controlled reaction varies with time

  Should be sufficient for an intimate contact to be formed and for the diffusion process to take place.

DIFFUSION BONDING OPERATION

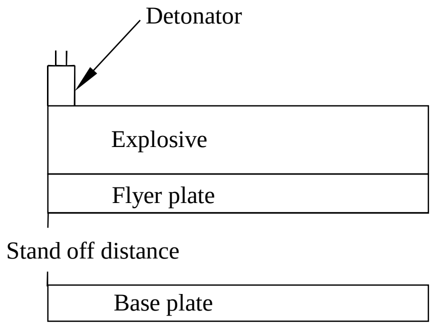
EXPLOSIVE BONDING

Explosive Welding/Cladding

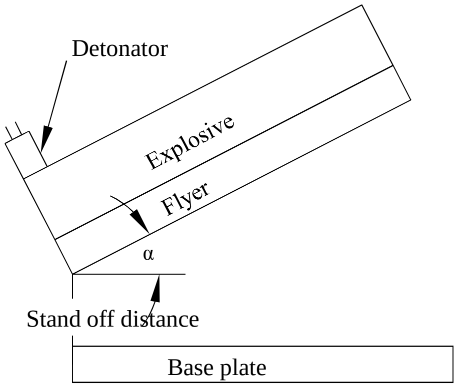
- **Controlled energy of a detonating explosive is used to create a metallurgical bond between two or more similar or dissimilar metals**
- **Quality of explosively produced weld primarily depends on the state of interface between the components**

Types of Welding setup

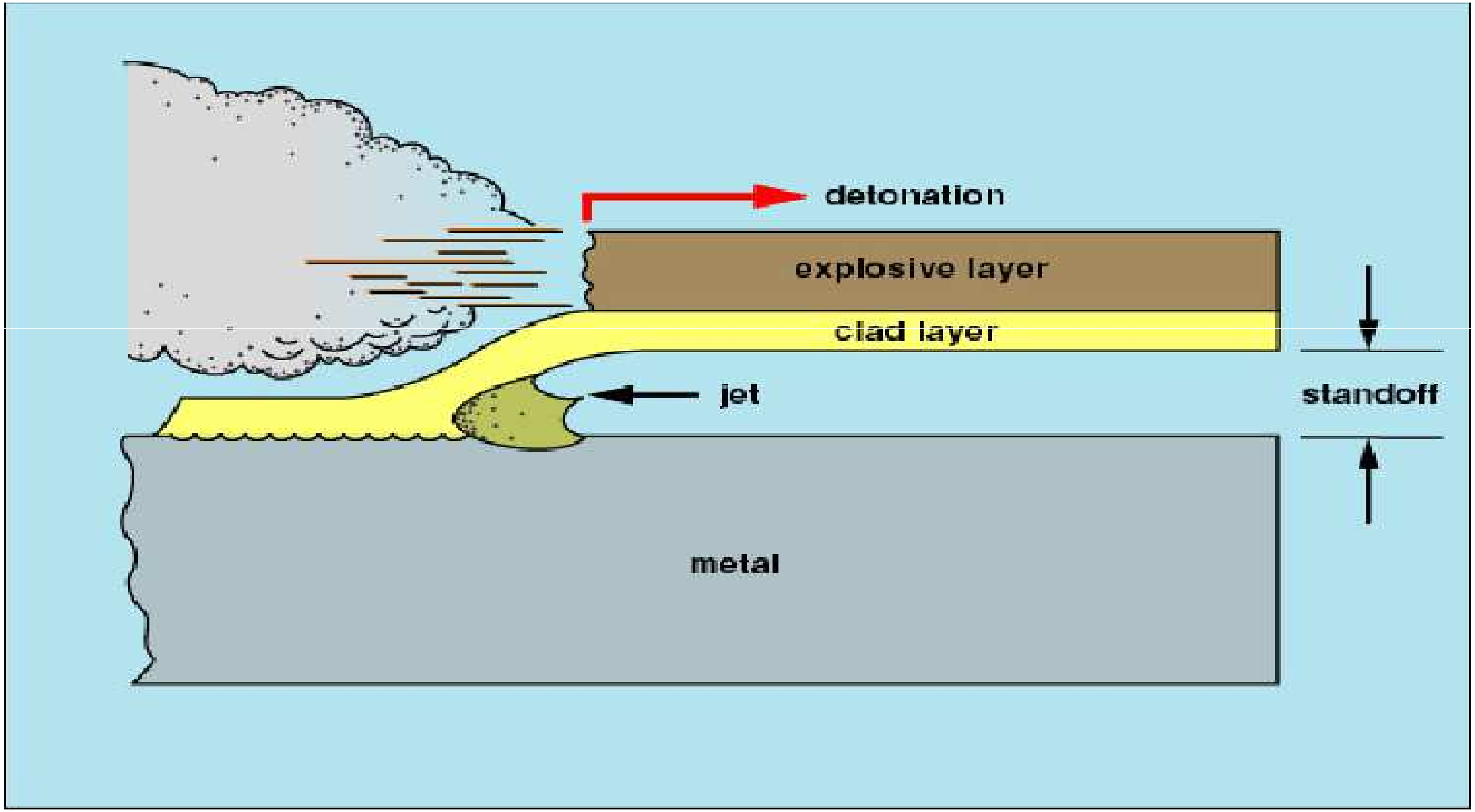
- Parallel setup

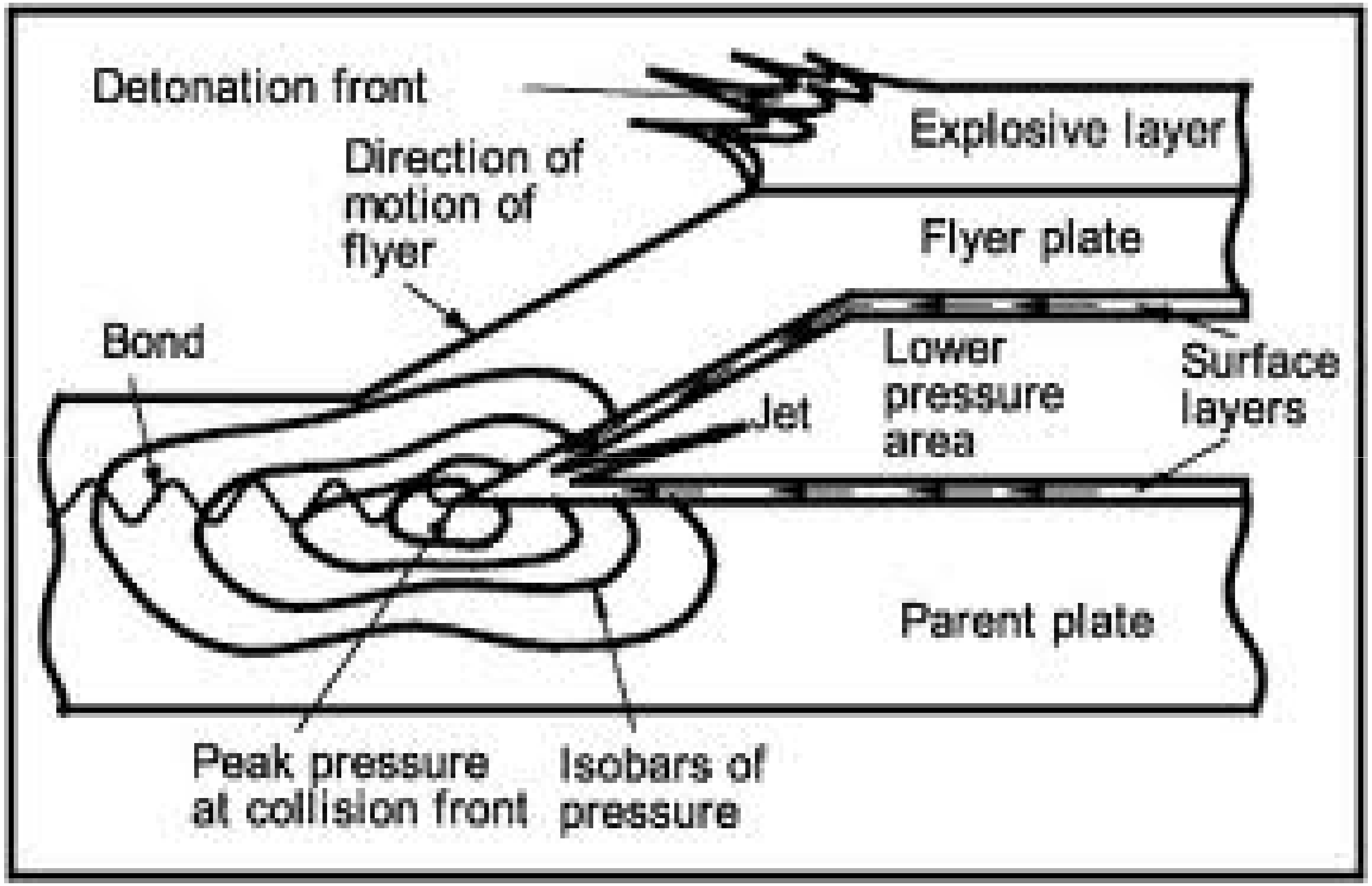


- Inclined setup



Explosive Welding and Cladding

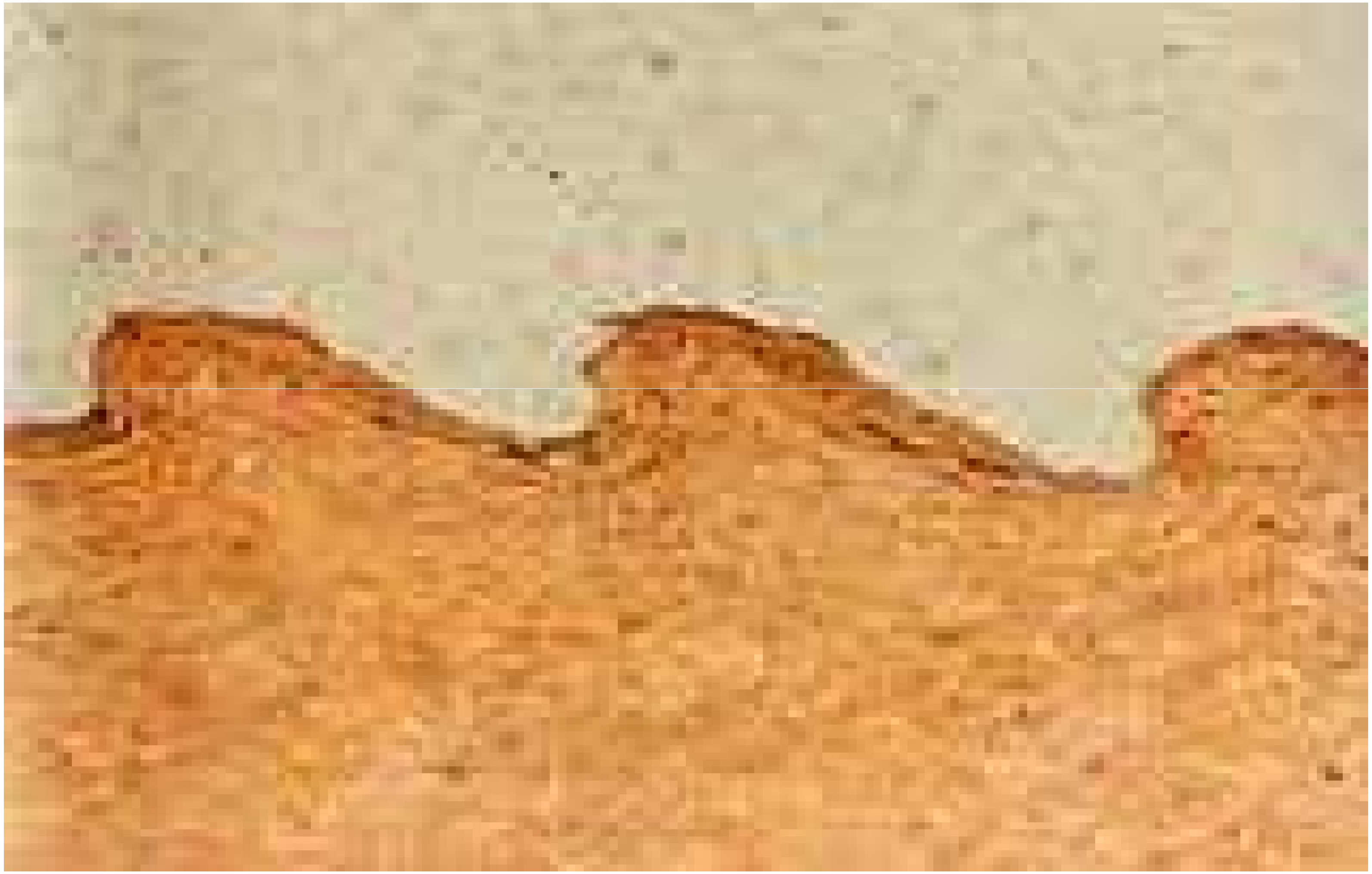




Detonation front
Explosive layer
Direction of motion of flyer
Flyer plate
Bond
Lower pressure area
Surface layers
Jet
Parent plate
Peak pressure at collision front
Isobars of pressure

EXPLOSIVE BONDING : ANIMATION

AUMINIUM BONDED WITH COPPER



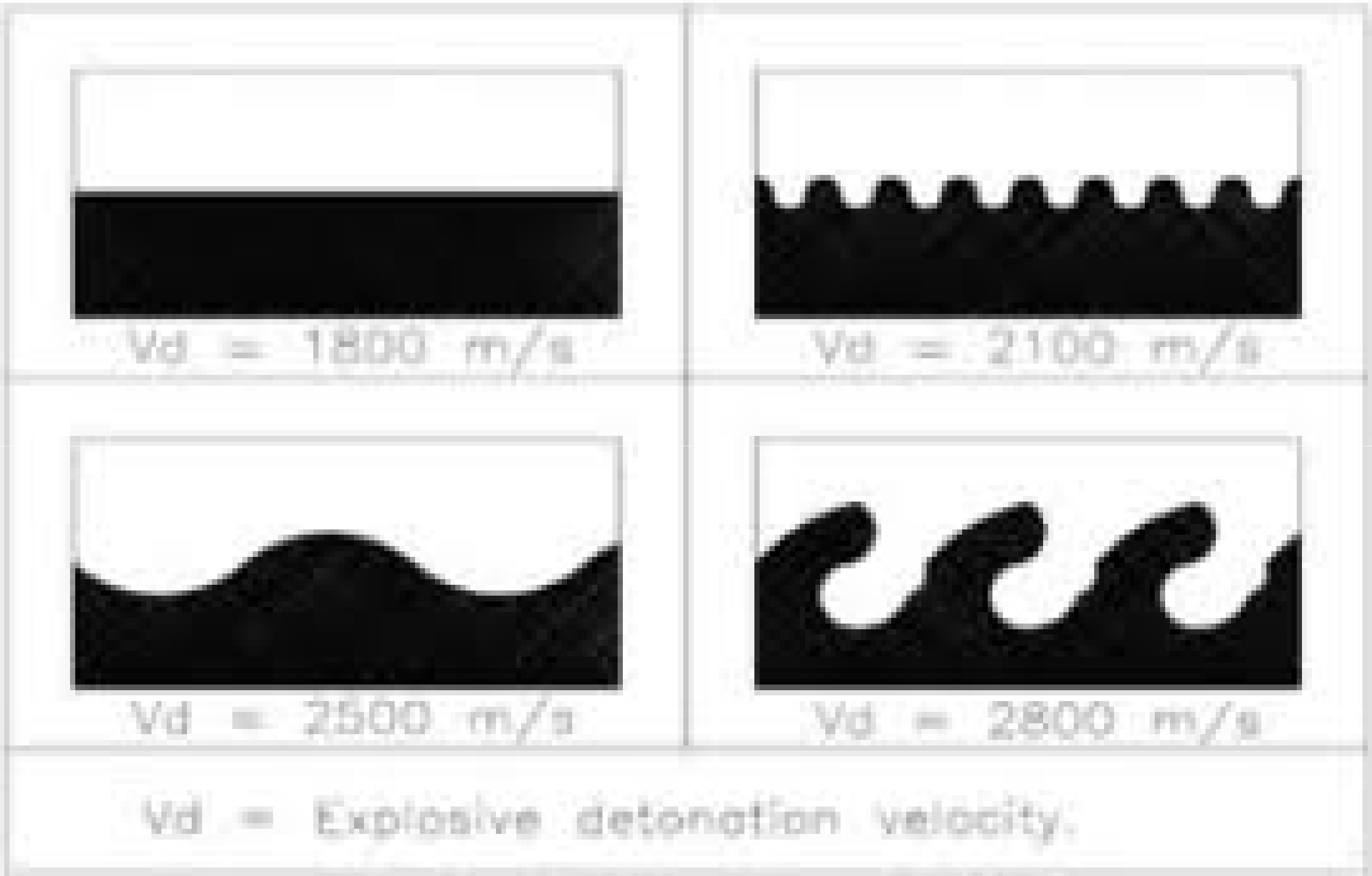
Parameters

- Explosive
- Explosive Loading (e/m)
- Collision point velocity
- Collision angle
- Thickness of flyer plate
- Stand off distance
- Flyer velocity
- Thickness of parent plate
- Anvil
- Surface finish

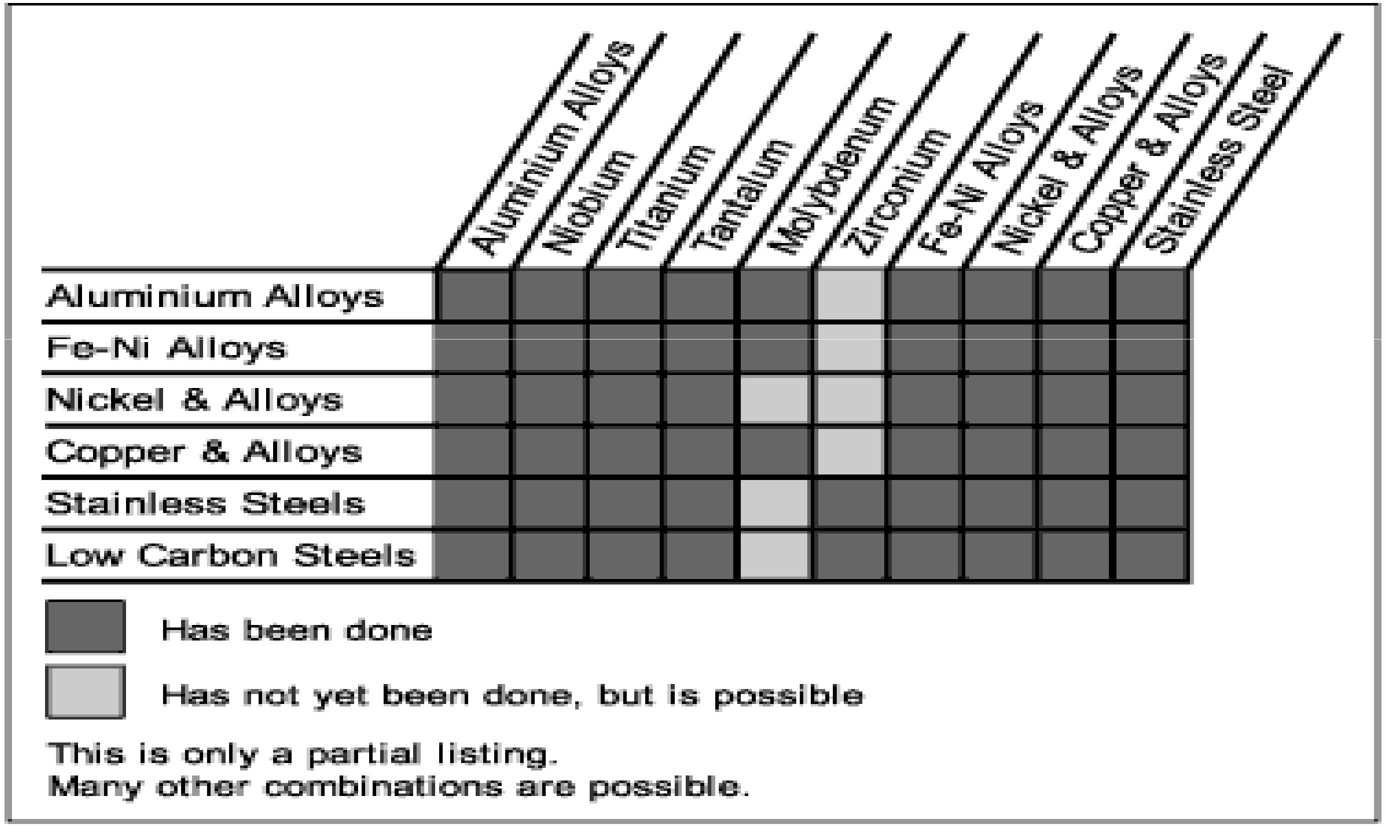
Explosives

The commonly used explosives are

Explosive	Detonation velocity , m/s
1) RDX	8100
2) PETN	8190
3) TNT	6600
4) Tetryl	7800
5) Lead azide	5010
6) Detasheet	7020
7) Ammonium nitrate	2655
8) Special Gelatine	2000


Vd = 1800 m/s
Vd = 2100 m/s
Vd = 2500 m/s
Vd = 2800 m/s
Vd = Explosive detonation velocity.

Common clad combinations

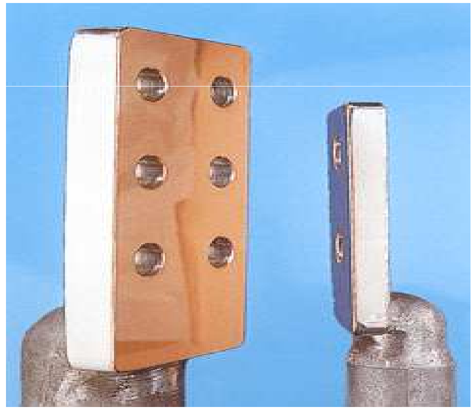


Advantages

+ Similar and dissimilar metals can be welded
+ Weld area is not restricted
+ Metals having different melting points can be cladded
+ Metals with different properties can be welded
+ Joint strength is higher than weaker of the two metals
+ Suited for bonding flat and cylindrical surfaces

APPLICATIONS OF EXPLOSIVE CLADDING

- Chemical Process vessels
- Marine applications
- Tube welding and plugging
- Pipeline welding
- Electrical Applications
- Transition Joints
- Attaching cooling fins
- Pressure vessel, Heat exchanger tube sheets



APPLICATIONS OF EXPLOSIVE BONDING

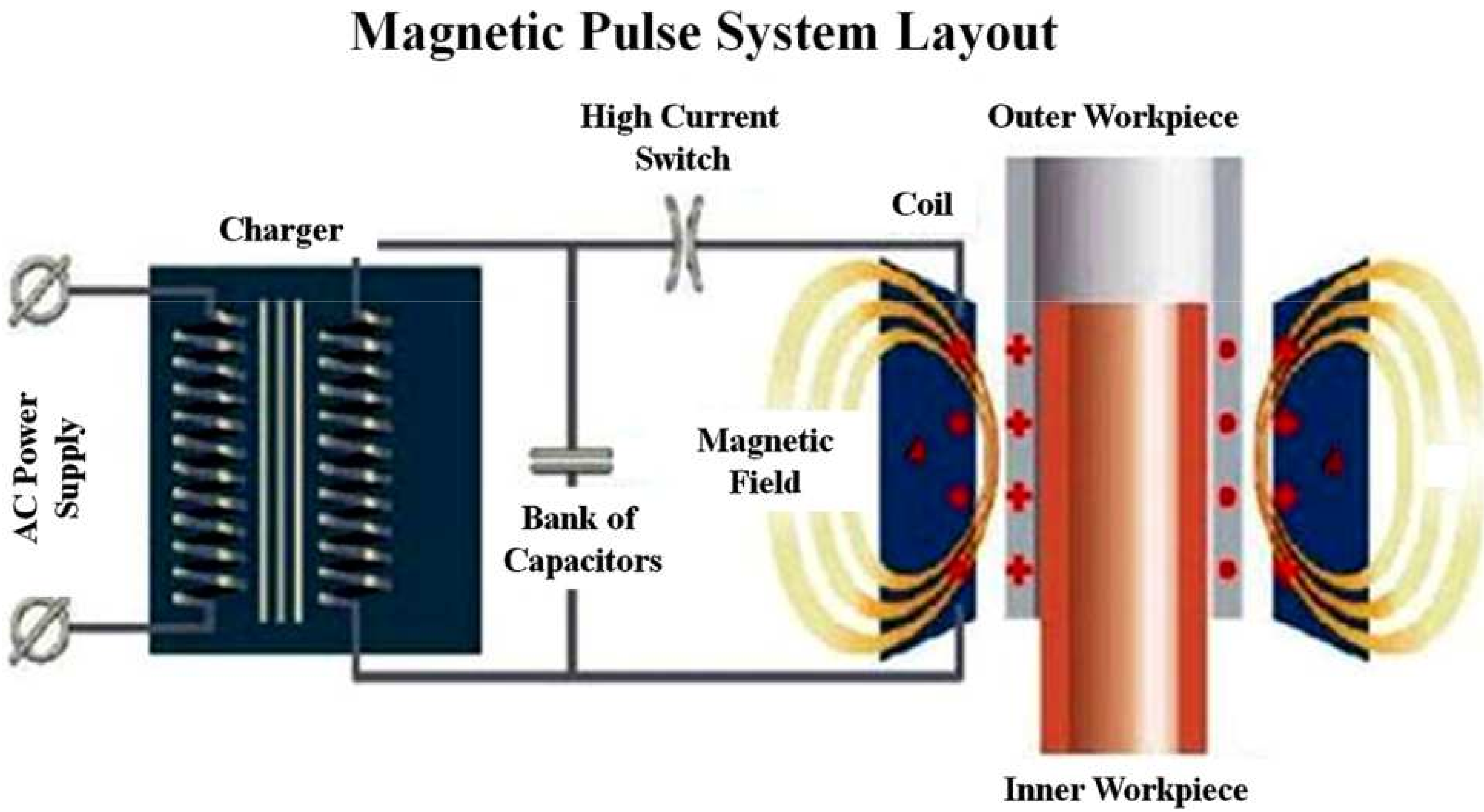
Magnetic Pulse Welding

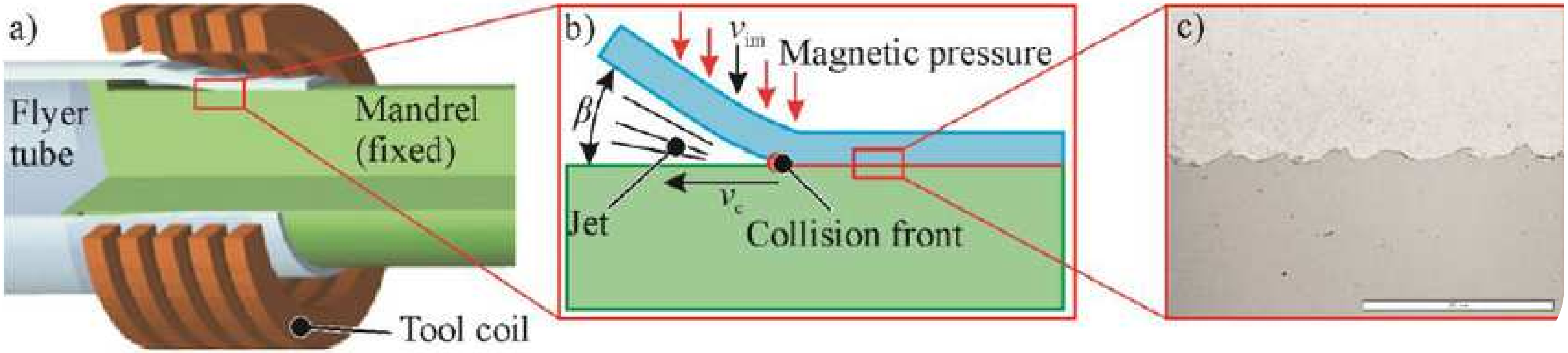
Magnetic Pulse Welding

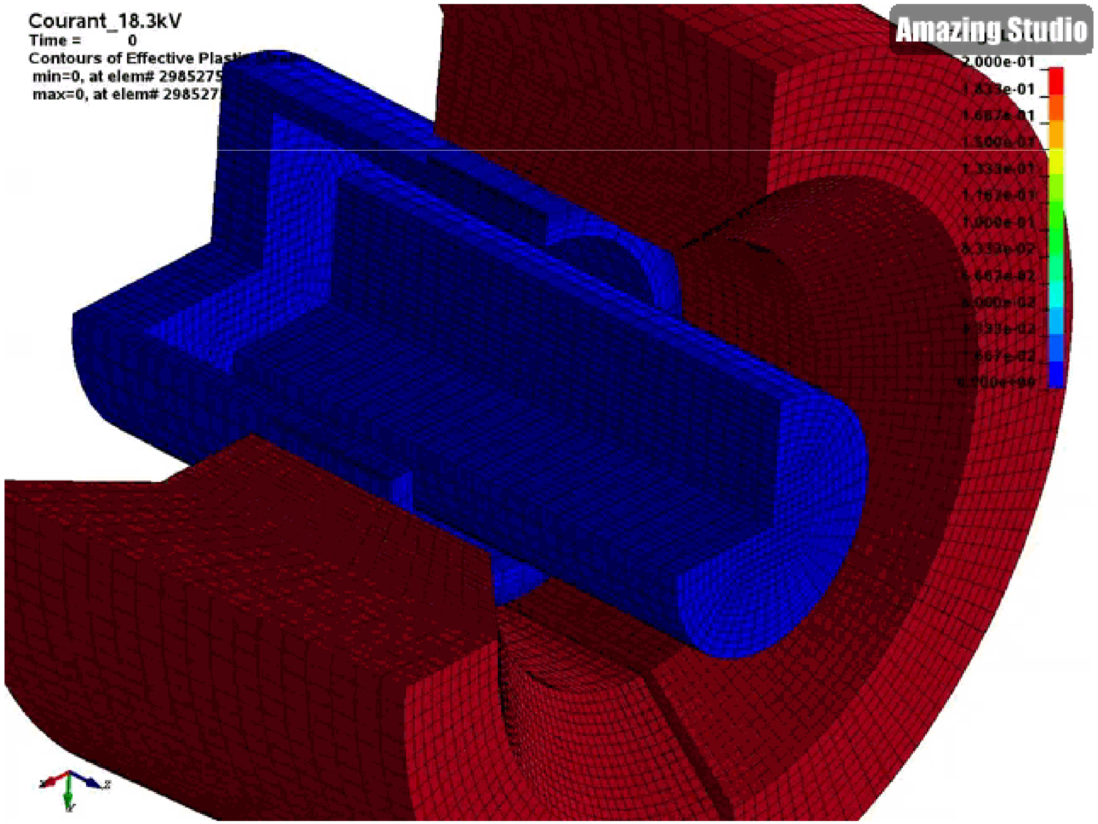
- **The concept of discharging a large amount of electrical energy through a coil during a very short period of time, a high density magnetic flux is produced.**

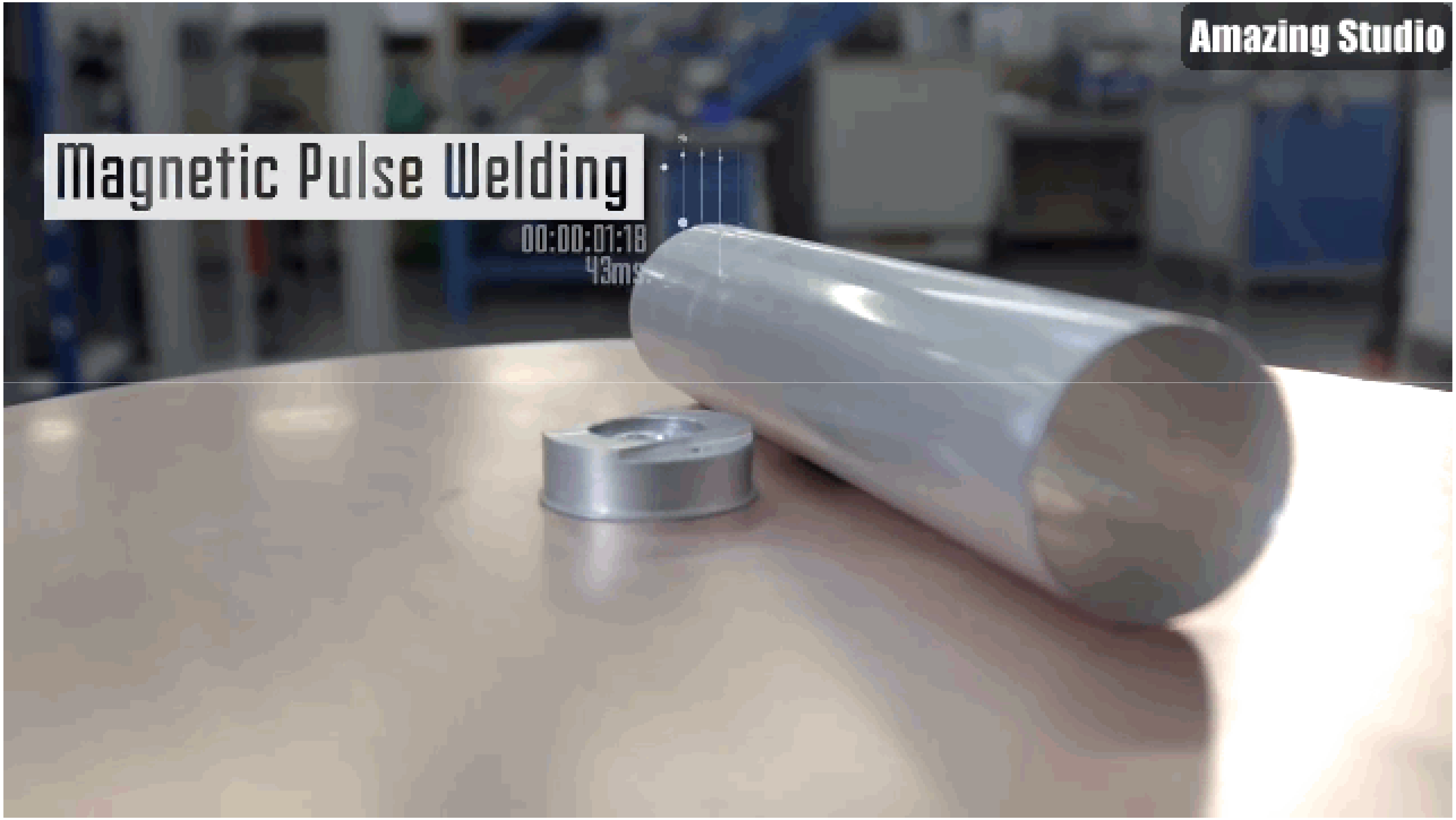
- **It is used to create a metallurgical bond between two similar (or) dissimilar metals.**

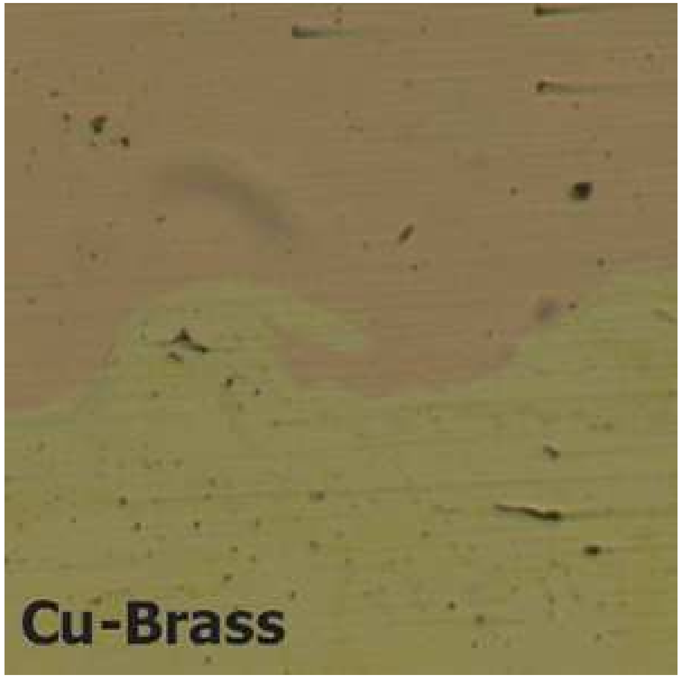
Magnetic Pulse System Layout

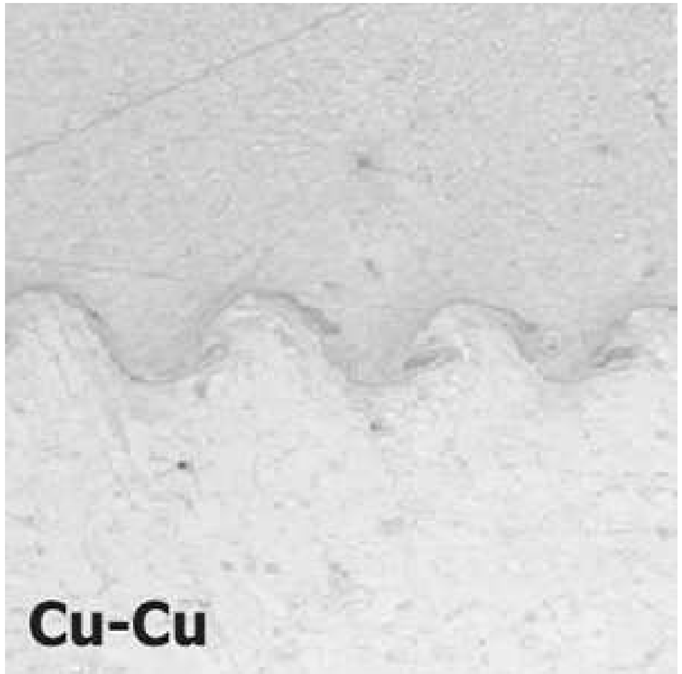


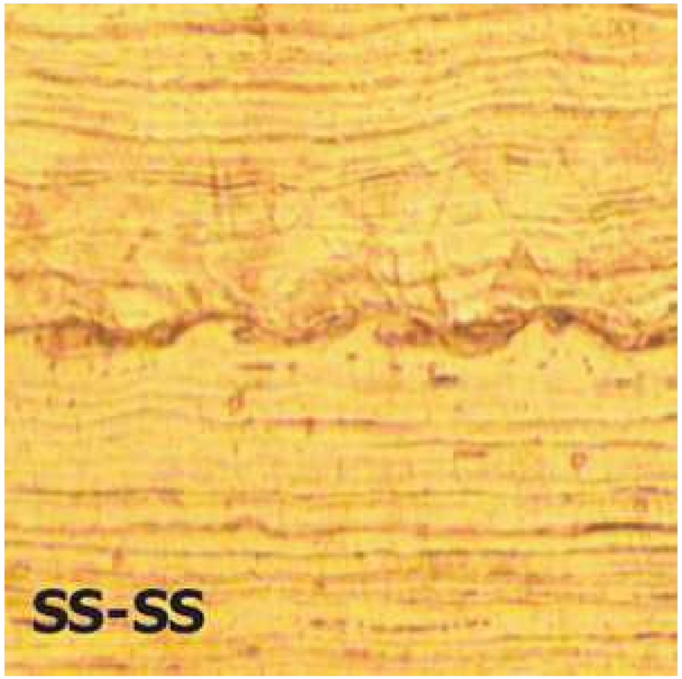

a)
Flyer tube
Mandrel (fixed)
Tool coil
b)
v_{im}
Magnetic pressure
β
Jet
v_c
Collision front
c)

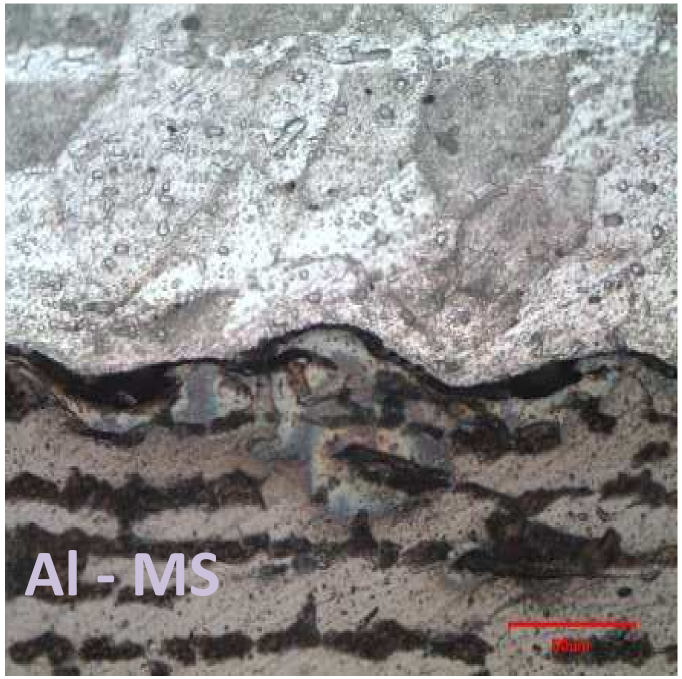

Courant_18.3kV
Time = 0
Amazing Studio
2.000e-01


Amazing Studio
Magnetic Pulse Welding
00:00:01:18
43ms


Cu-Brass

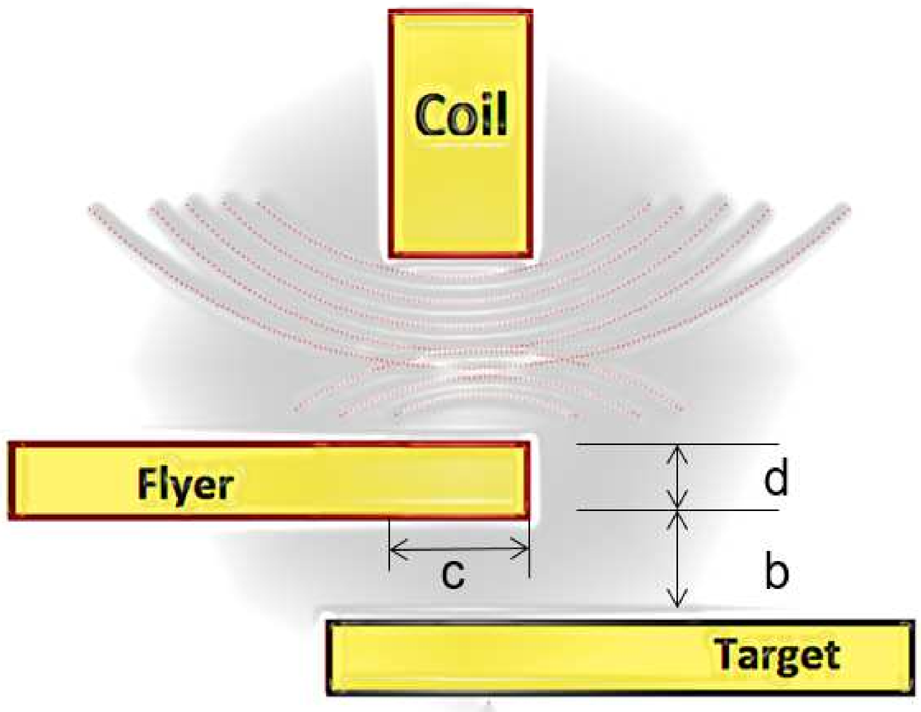

Cu-Cu


SS-SS


Al - MS

Process Parameters

a) Voltage (kV)
b) Stand-off distance (mm)
c) Working Length (mm)
d) Flyer thickness (mm)



Advantages

- High-speed (a typical pulse lasts from 10 to 100μs)
- High repeatability
- Reliable and well suited to high-volume production
- Dissimilar metals are possible
- Cold weld with no heat-affected zone
- No need for filler materials
- Green process (no heat, no sparks, no smoke, no radiation)
- Clean process (no pre- or post-weld cleaning)
- High quality, very aesthetic and cleaner interface
- No distortion
- Lower costs and productivity

Applications

Drive Shaft

Air Filter

SS - Al

FRICTION STIR WELDING

FRICTION STIR WELDING (FSW) PROCESS

- **FSW process was invented by The Welding Institute (TWI), UK in 1991.**

- **It is an emerging solid state joining process in which the material that is being welded does not melt and recast.**

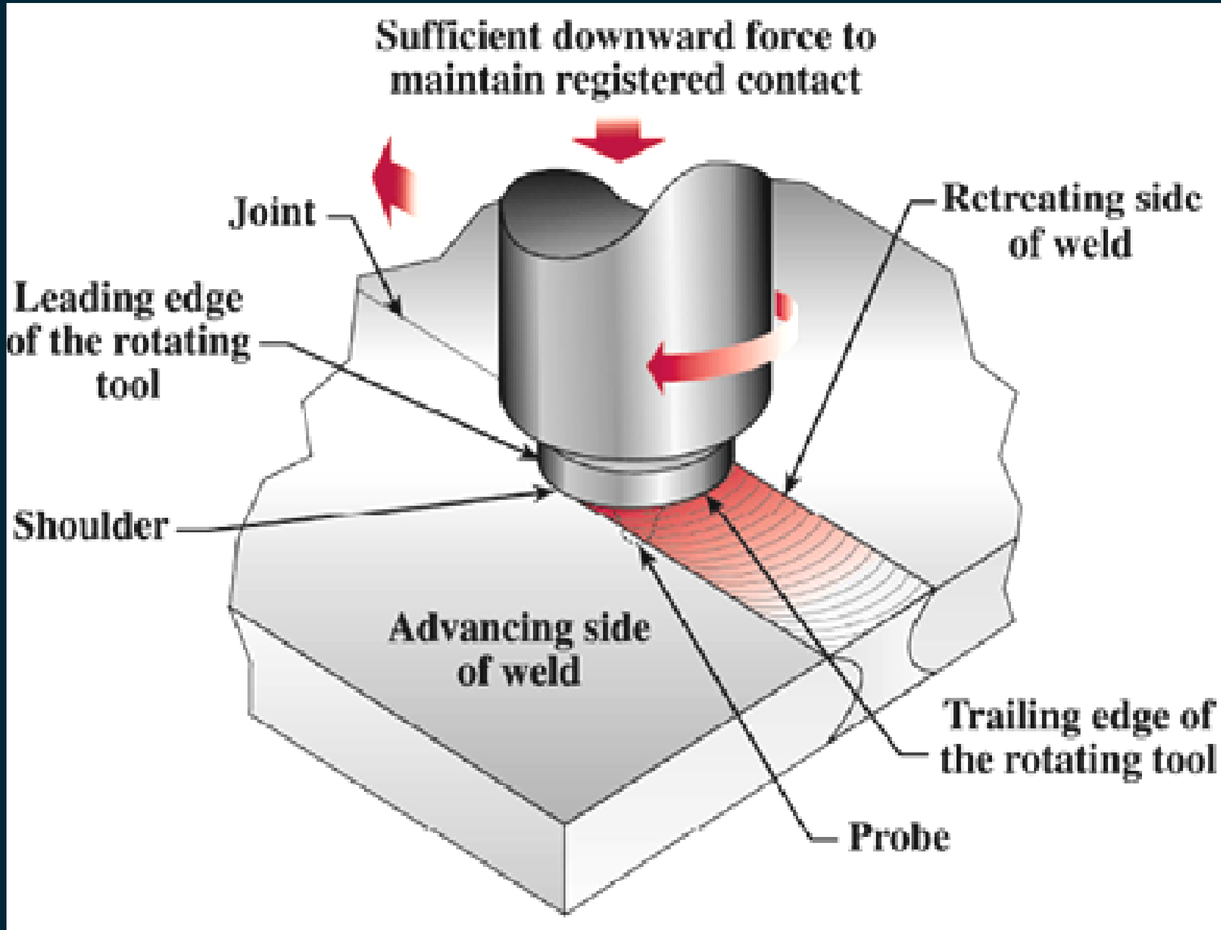
- **It is a hot shear autogenous process.**

- **There is no need of filler metals, shielding gases and there is no need of profiled edge preparation.**

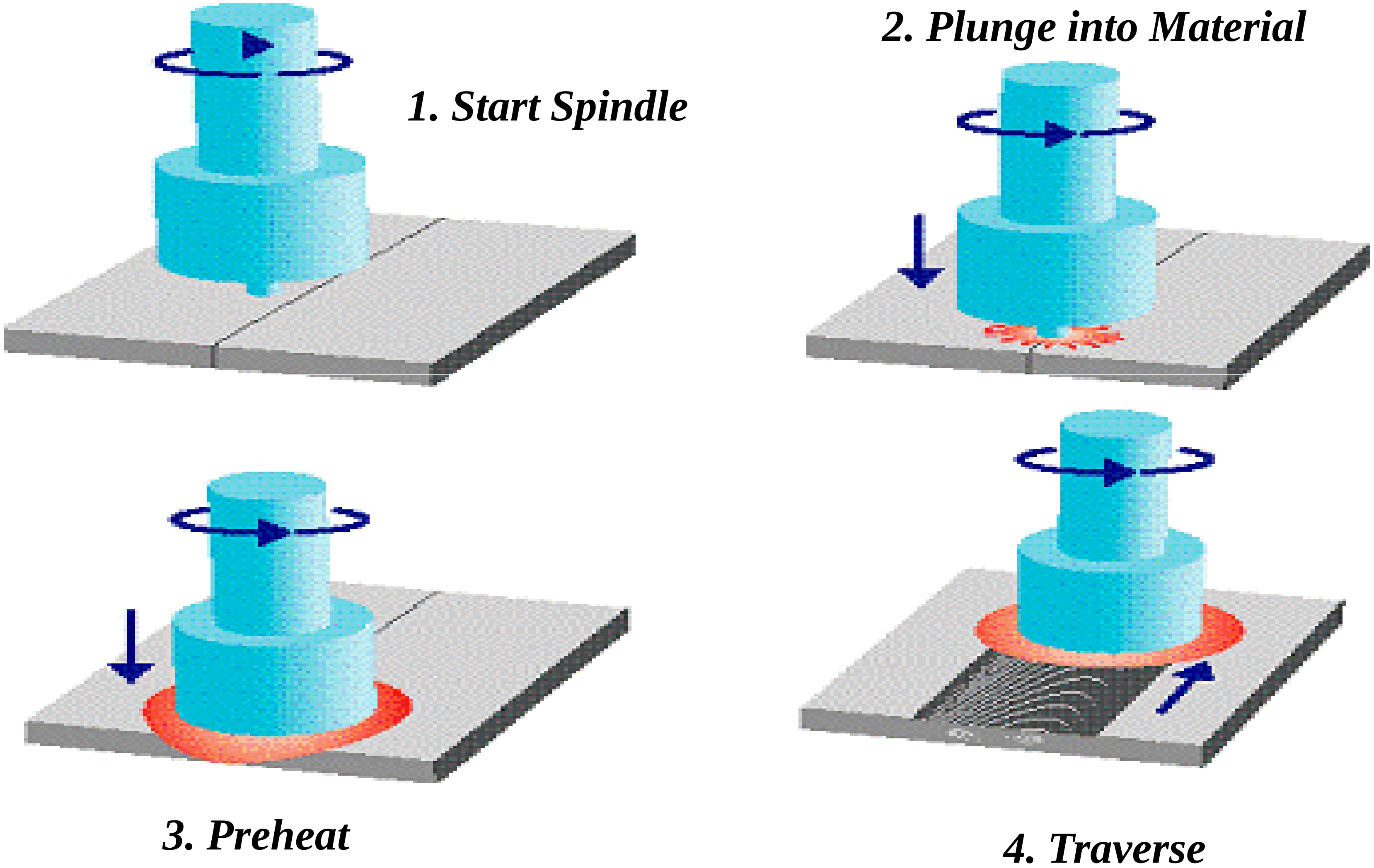
- **This process produces no smoke, fumes, arc glare and it is an environmentally cleaner welding process**

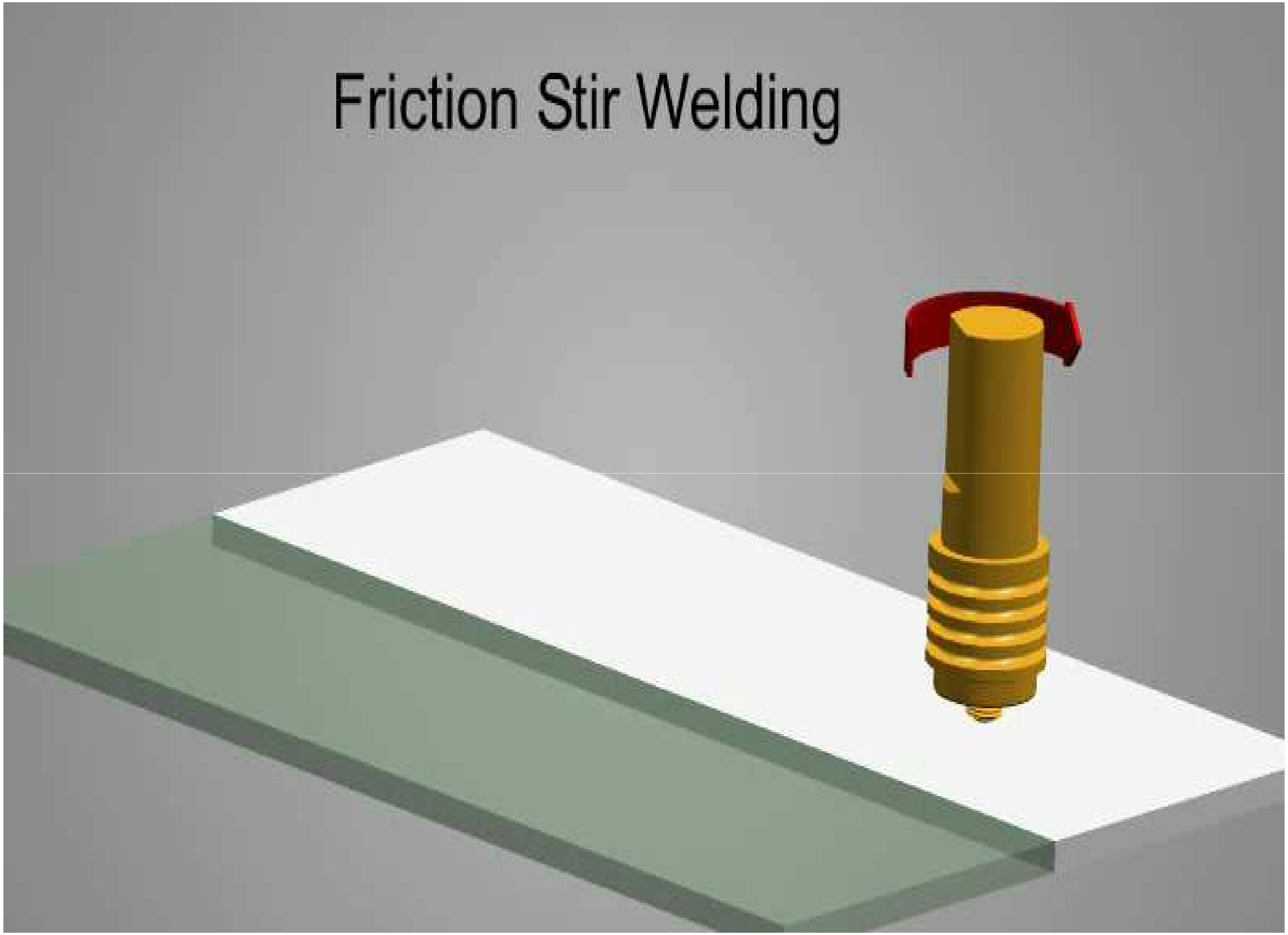
Terminology of FSW

- Tool Pin
- Tool Shoulder
- Advancing side
- Retreating side
- Downward force
- Leading Edge
- Trailing Edge
- Joint line



FSW Process Steps

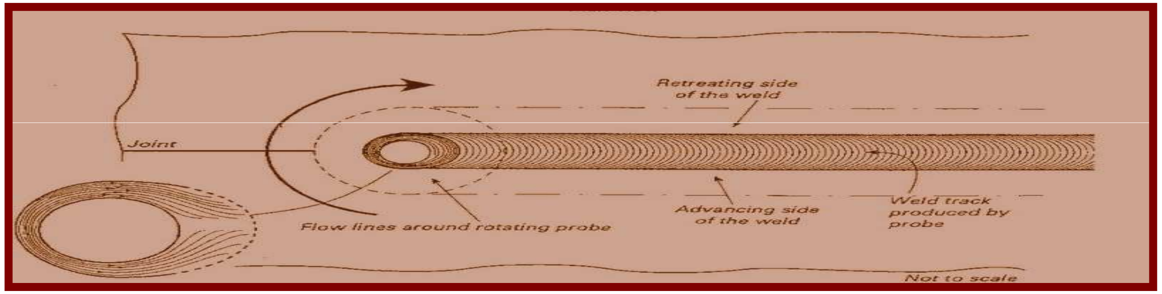



Friction Stir Welding

Principle of FSW

Shoulder: generates the necessary heat and controls the flow of the material.

Probe: stirs the material and thereby deform it, but also contribute with friction heat to the weld.



- The softened material underneath the shoulder is subjected to <u>extrusion</u> by the rotation of the tool and the traverse movement.
- The tool can be tilted from the vertical position to increase the <u>forging</u> action.
- The plasticised material is transferred from the leading edge of the tool to the trailing edge of the tool probe.

Friction Stir Welding (FSW) Machine
(Sponsored by AICTE-RPS, 2004)

CNC FSW MACHINE

(Sponsored by Ministry of Environment & Forests, Govt. of India, 2008)

FSW of Al Vs Steel

PARAMETERS AFFECTING THE WELD QUALITY

PROCESS PARAMETERS:

- ROTATIONAL SPEED
- WELDING SPEED
- AXIAL FORCE

TOOL PARAMETERS:

- TOOL PIN PROFILE
- TOOL SHOULDER DIAMETER

MATERIAL PARAMETERS:

- TOOL MATERIAL (HARDNESS)
- BASE MATERIAL (YIELD STRENGTH)

Heat Generation during FSW

(Heurtier et al., 2006)

$$q = (2\pi / 3S) \times \mu \times P \times \omega \times R_s \times \eta$$

S - welding speed in mm / sec

μ - co-efficient of friction

P - Normal force in ‘KN’

ω - Rotational speed in rev/sec

R_s- Shoulder radius in ‘m’

EFFECT OF WELDING PARAMETERS

High Heat Generation	High Rotational Speed; Low Welding Speed; High Axial Force; High Shoulder Radius; High μ	Turbulent Material Flow; Grain Coarsening; Precipitates Agglomeration; Excess Flash Formation; Formation of Defects such as Piping Defect, Tunnel Defect.
Low Heat Generation	Low Rotational Speed; High Welding Speed; Low Axial Force; Low Shoulder Radius; Low μ	No vertical flow of material; Poor weld metal consolidation; Formation of Defects such as Pin Holes, Kissing Bond, Lazy S, Cracks.
Optimum Heat Generation	Optimise above parameters	Proper Material Flow; Good consolidation of weld metal; Defect Free Welds.

PHASE 3:

CASE STUDIES

Case Study – 1:

WELDING OF ALUMINIUM ALLOY

(AA2219 T87)

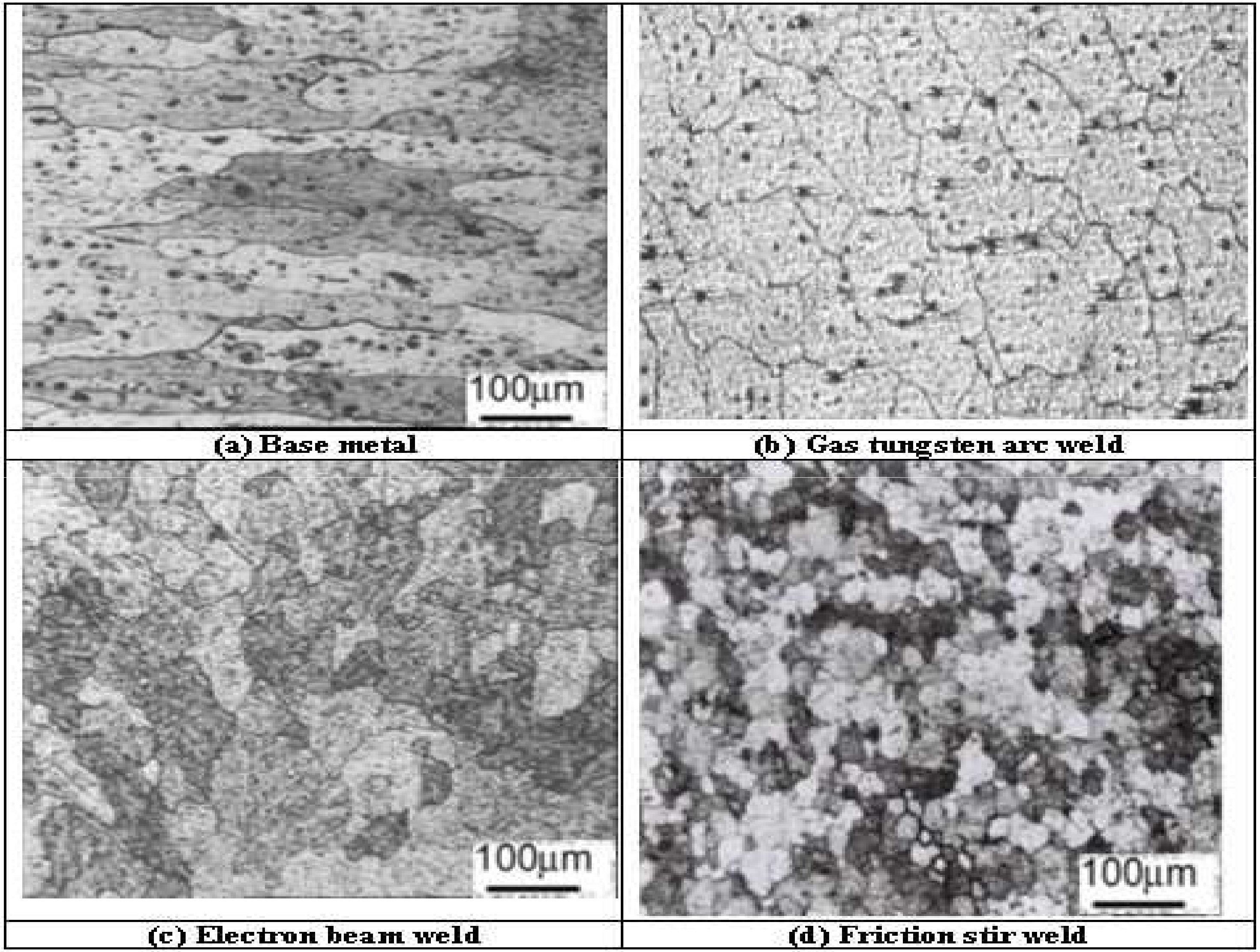
PROBLEMS IN WELDING OF AA2219

- **Though AA2219 has got an edge over its counterparts in terms of weldability, it also suffers from poor as welded joint strength.**
- **The joint strength is only about 50% when compared to the base metal strength in T87 condition.**
- **This is true both in autogenous welds as well as those welded with the matching filler 2319.**
- **The gap between strength values of the base metal and weld metal is significantly large.**
- **This forces the design engineers to use thicker plates, which in turn increases the total weight of the structure.**

Transverse tensile properties of welded AA2219 aluminium alloy joints

Joint Type	Yield strength (MPa)	Ultimate tensile strength (MPa)	Elongation (%)	Reduction in cross sectional area (%)	Notch tensile strength (MPa)	Notch strength ratio (NSR)	Joint Efficiency (%)
BM	392	475	15	10	442	0.93	---
GTAW	220	242	8.8	6.2	182	0.75	51
EBW	265	304	10.4	7.5	243	0.80	64
FSW	305	342	12.2	8.6	291	0.85	72

OPTICAL MICROGRAPHS OF WELD REGION



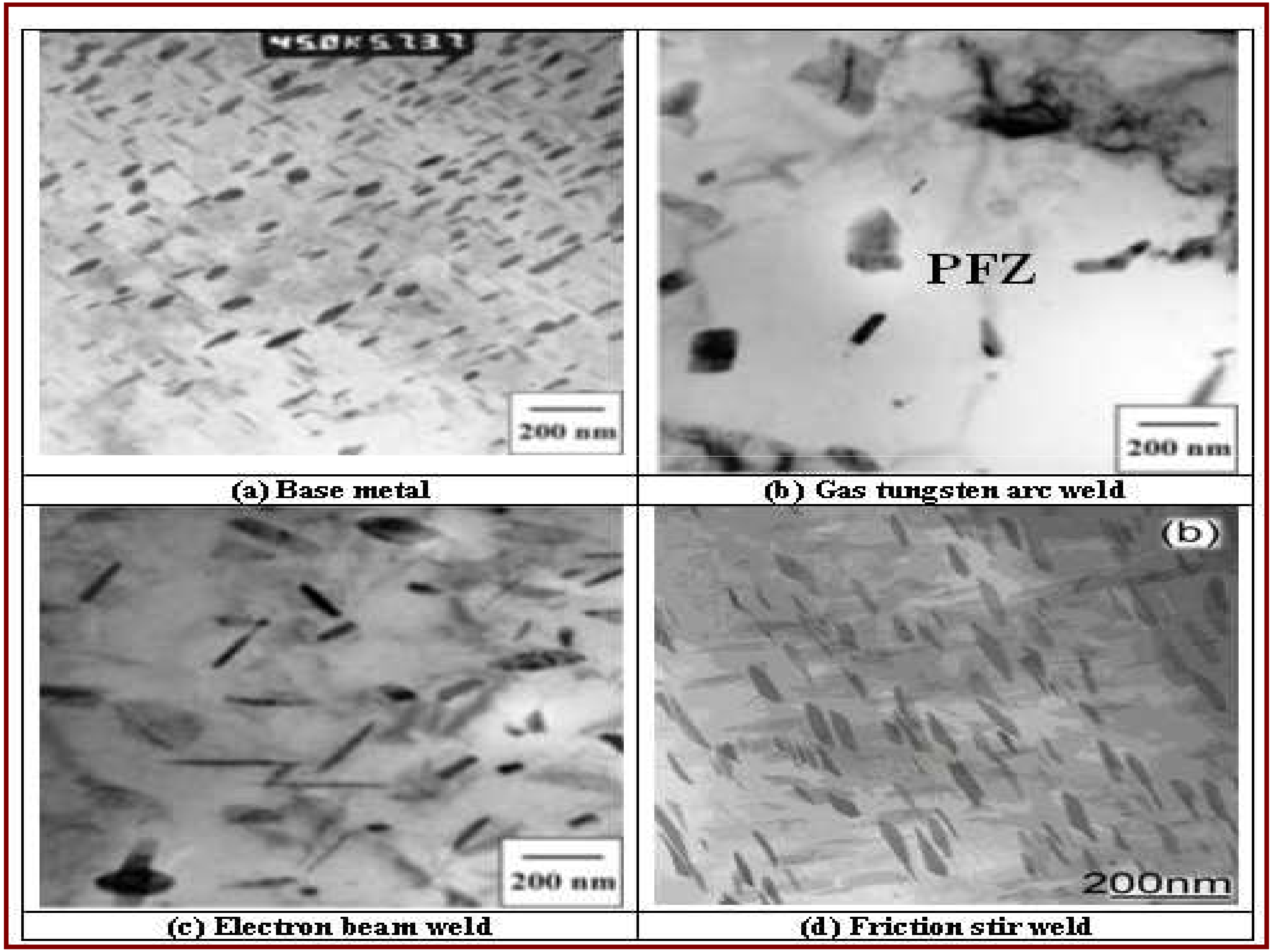
(a) Base metal

(b) Gas tungsten arc weld

(c) Electron beam weld

(d) Friction stir weld

TRANSMISSION ELECTRON MICROGRAPHS OF WELD REGION



(a) Base metal

(b) Gas tungsten arc weld

(c) Electron beam weld

(d) Friction stir weld

IMPORTANT FINDINGS

- **As welded FSW joint exhibits the maximum joint efficiency of 72% which is 40% higher than GTAW joint and 12% higher than EBW joint. As welded FSW joint exhibits the maximum fatigue strength of 180 MPa which is 20% higher than EBW joint and 50% higher than GTAW joint.**

- **Post weld aging treatment (PWA) was found to be beneficial to enhance the tensile strength and fatigue strength of as welded (AW) joints, approximately 10-12%. It is also beneficial to reduce the severity of notches under fatigue loading.**

Case Study – 2:

WELDING OF MAGNESIUM ALLOY

(AZ 31B)

.

PRESENT SCENERIO

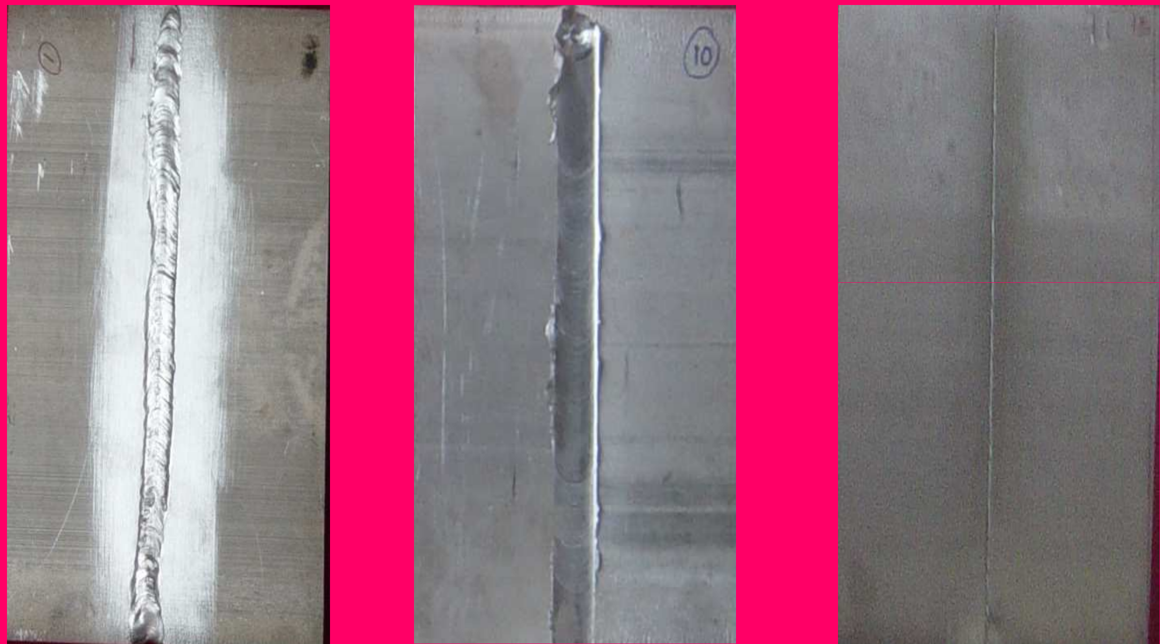
- **Magnesium (Mg) alloys have recently received considerable attention due to their excellent properties such as light weight, high specific strength and stiffness, machinability and recyclability.**

- **These advantages make magnesium alloys very attractive as structural materials in a wide variety of applications, where weight reduction is extremely important.**

- **However, magnesium alloys are currently still not as popular as aluminium alloys in structural applications and a major technical challenge is the development of reliable and inexpensive joining methods producing high quality welds.**

- **Conventional welding methods produce some defects like porosity and hot crack, which deteriorate their mechanical properties.**

JOINTS OF AZ31B MAGNESIUM ALLOY



GTAW **FSW** **LBW**

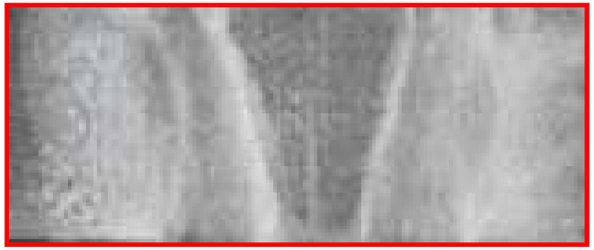
MECHANICAL PROPERTIES OF AZ31B Mg ALLOY

Yield strength (MPa)	Ultimate tensile strength (MPa)	Elongation (%)	Reduction in cross - sectional area(%)	Notch tensile strength (MPa)	Notch Strength Ratio (NSR)	Hardness (HV) at 0.05 kg load
172	215	14.7	12.4	192	0.89	69.3

TRANSVERSE TENSILE PROPERTIES OF JOINTS

Joint Type	*Yield strength (MPa)*	*Ultimate tensile strength (MPa)*	*Elongation (%)*	*Reduction in c.s.a (%)*	*Notch tensile strength (MPa)*	*Notch strength ratio (NSR)*	*Joint Efficiency (%)*
GTAW	148	183	7.6	5.9	156	0.85	85.1
FSW	171	208	11.8	8.7	181	0.87	96.7
LBW	174	212	12.1	9.4	187	0.88	98.6

MACROSTRUCTURE OF WELDED JOINTS (10X)

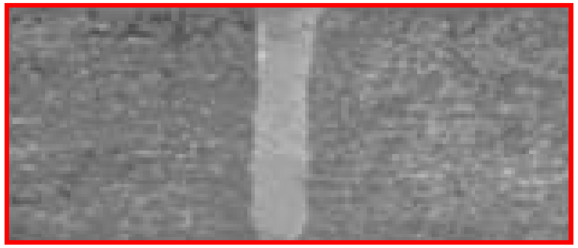


GTAW

- TRAPEZOIDAL SHAPED WELD REGION WITH FULL PENETRATION

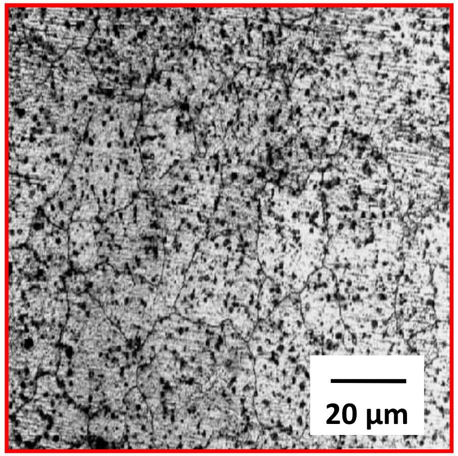
FSW

- MACROSTRUCTURE WITH HALF ELLIPTICAL NUGGET REGION.



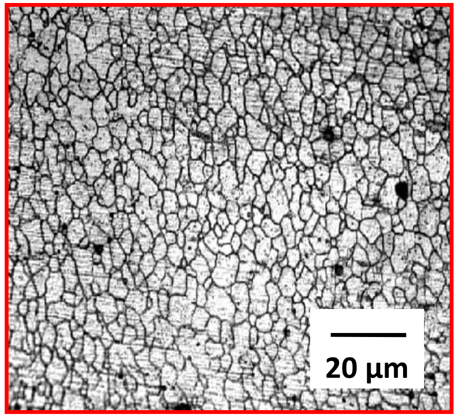
LBW

- NARROW WELD REGION WITH DEEPER PENETRATION.



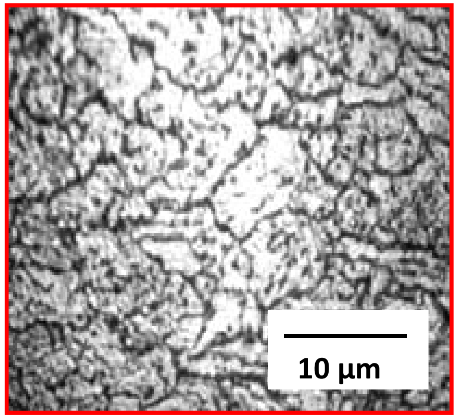
GTAW

- Contains coarser grains with $Al_{12}Mg_{17}$ precipitates (β phase) (Zhou et al. 2007)
  Grain Size : 10.2 µm
- Due to high heat input and slow cooling rate grain growth was occurred in weld region.



FSW

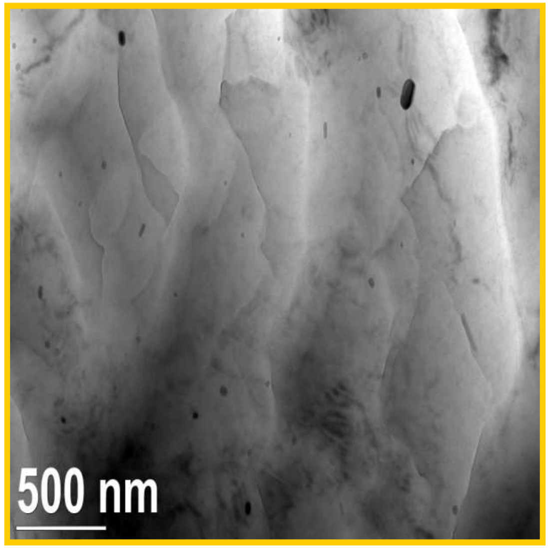
- Contains very fine, equiaxed grains
  Grain Size : 6.3 µm
- Due to the dynamic recrystallisation that occurred during FSW process



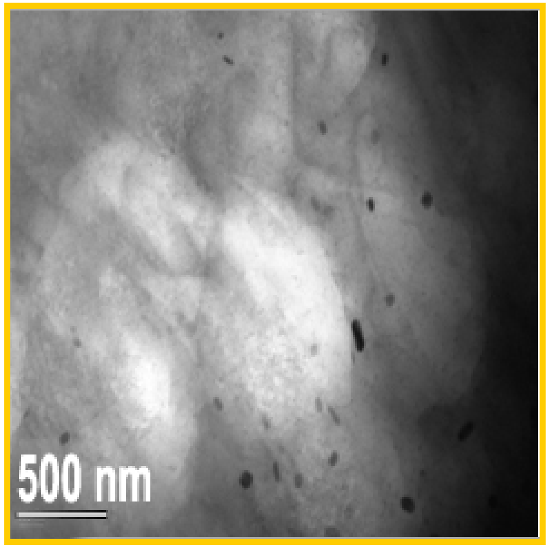
LBW

- Consists of fine equiaxed grains. Furthermore, evidence of a large number of precipitated particles ($Al_{12}Mg_{17}$) is also observed (Quan et al. 2008).
  Grain Size : 4.9 µm
- Due to high welding speed and fast recrystallization the fusion zone is characterized by very fine grains

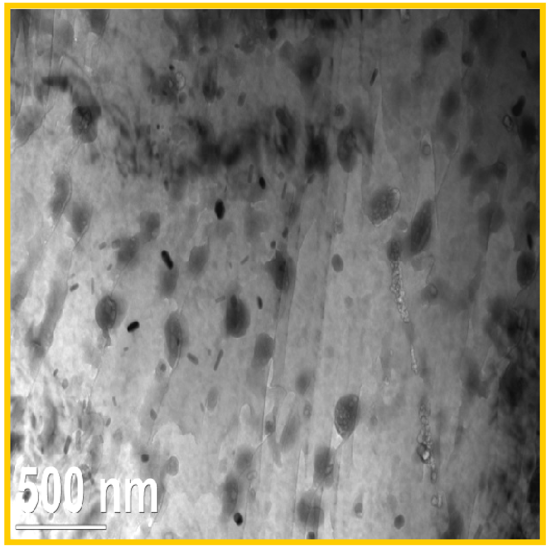
TEM MICROGRAPHS



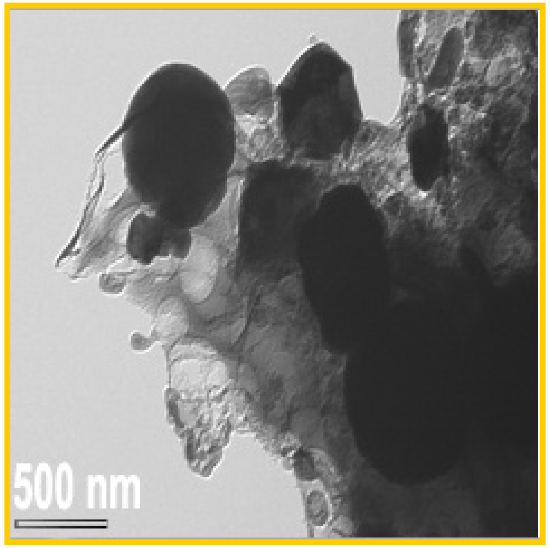
BASE METAL



FSW-STIR ZONE



LBW- FUSION ZONE



GTAW- FUSION ZONE

IMPORTANT FINDINGS

- **Of the three types of welded joints, the joints fabricated by LBW exhibited higher strength values, and the enhancement in strength is approximately 14% compared to GTAW joints and 2 % compared to FSW joints.**

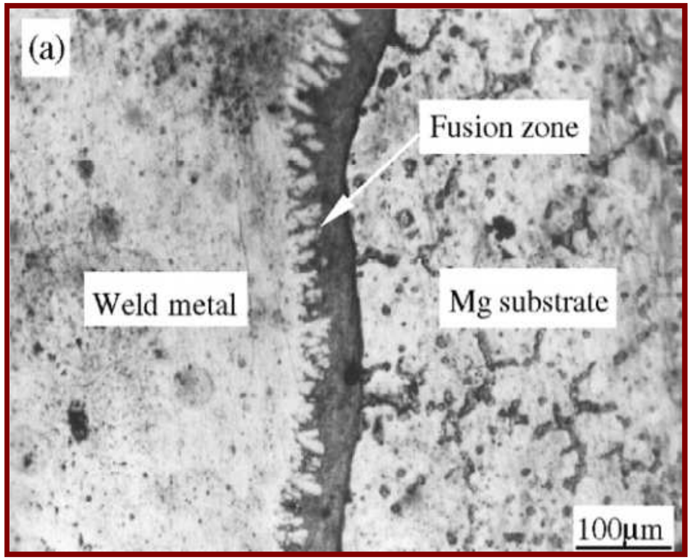
- **The formation of very fine grain microstructure, higher fusion zone hardness and the absence of heat affected zone are the main reasons for superior tensile properties of LBW joints compared to GTAW and FSW joints.**

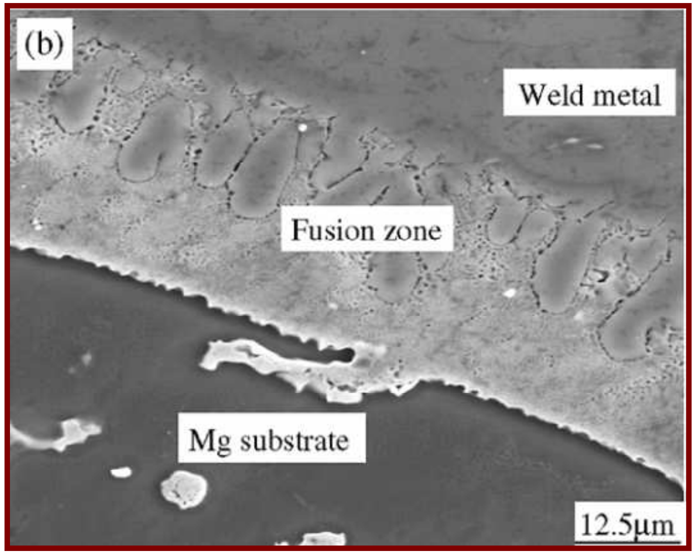
Case Study - 3

FRICTION STIR WELDING OF DISSIMILAR MATERIALS

(AA 6061 with AZ 31B)

GTAW WELDING



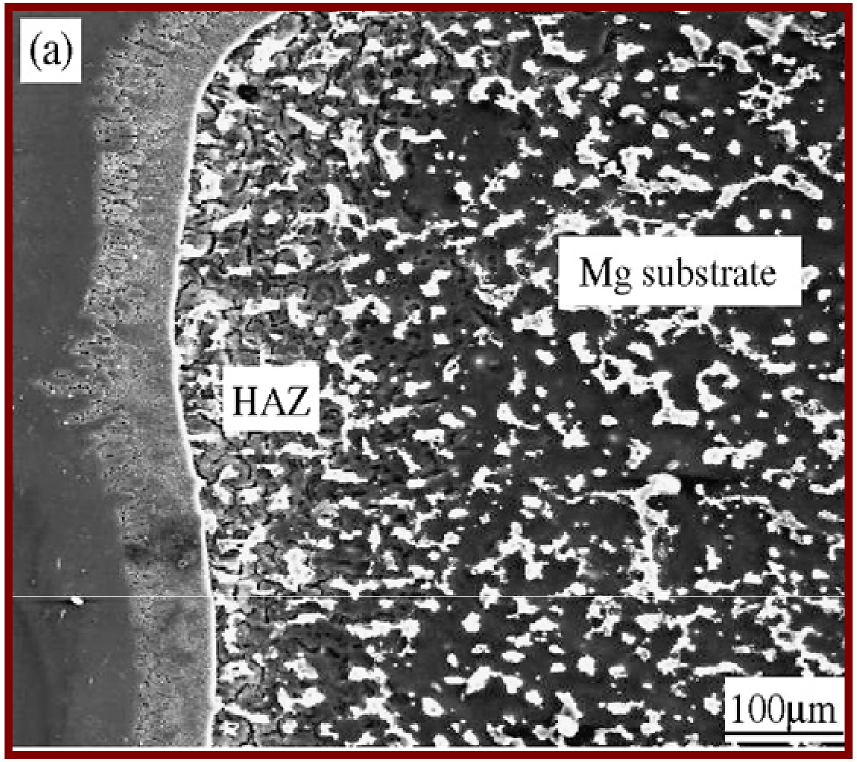


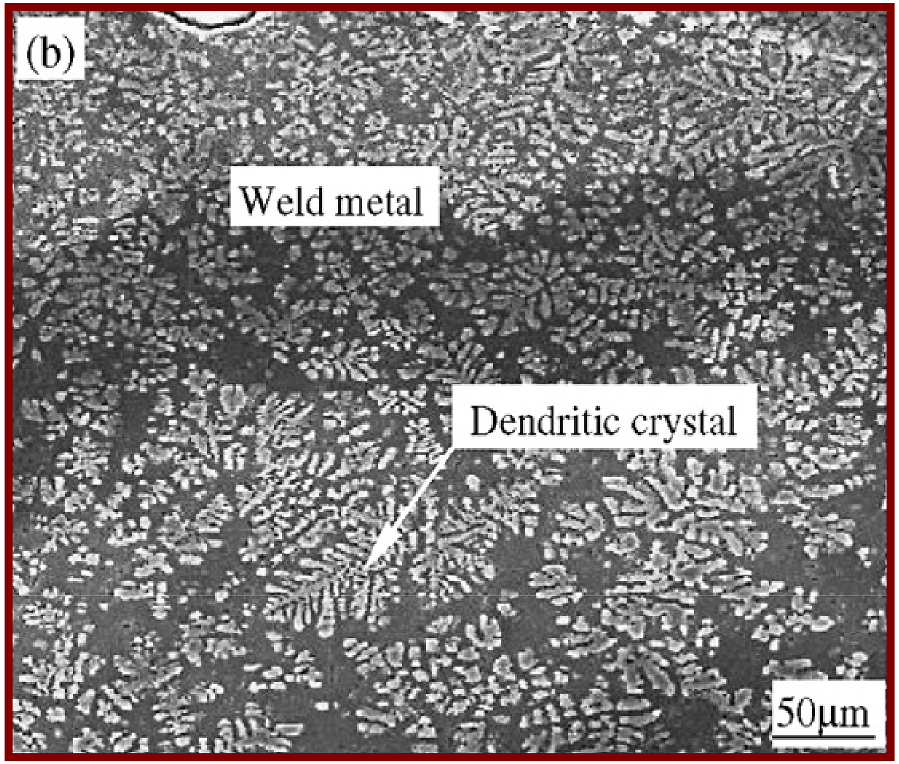
- There is an obvious boundary between weld metal and Mg substrate.

- The microstructure near the fusion zone is obviously different from the weld metal and Mg substrate, columnar crystals close to the weld metal are shown.

- The micro structure of the heat affected zone and weld metal for Mg/Al TIG welded was observed by SEM is shown. Fig a) shows microstructure between Mg substrate and fusion zone.

- Mg substrate close to the friction zone was largely affected by welding thermal cycle, the crystals were small far from the fusion was lesser and so microstructure was invariant by and large.

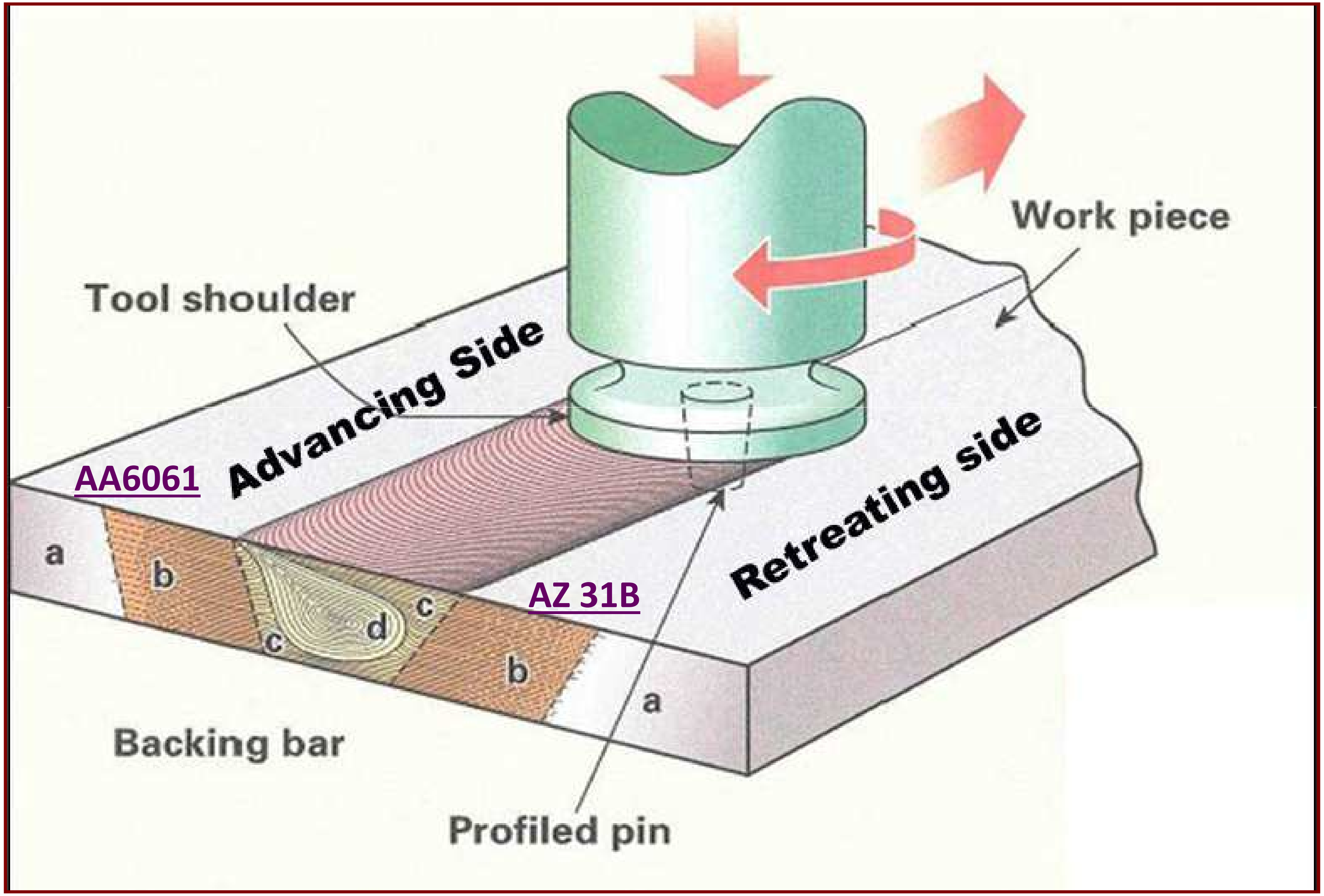




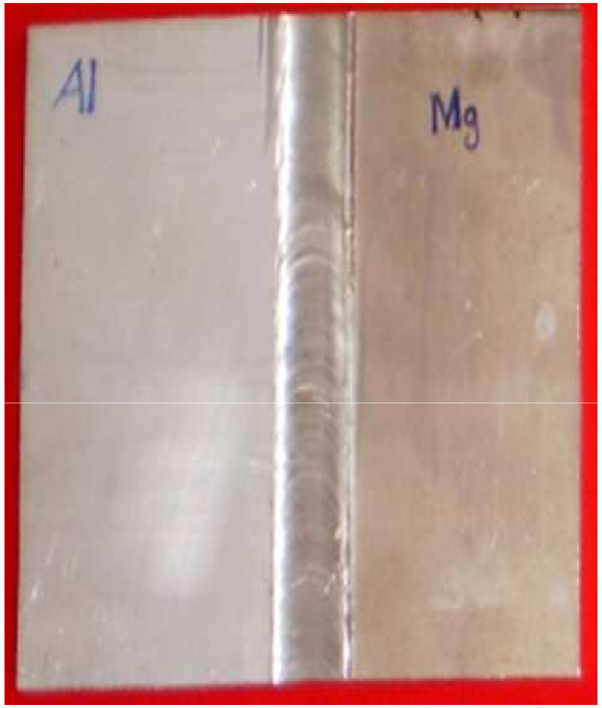
- The structure close to the weld metal is columnar crystals which grow into the weld metal.

- Weld metal was mainly composed of dendrite crystals.

SCHEMATIC REPRESENTATION OF FSW



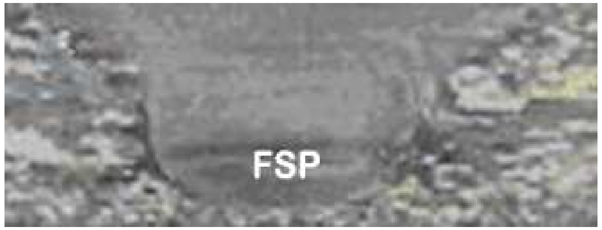
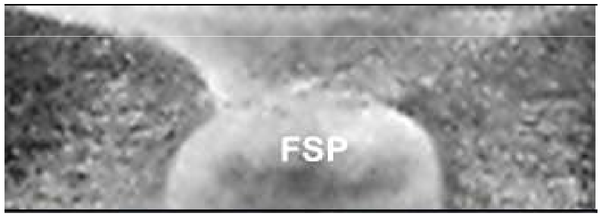
PHOTOGRAPH OF FABRICATED JOINTS



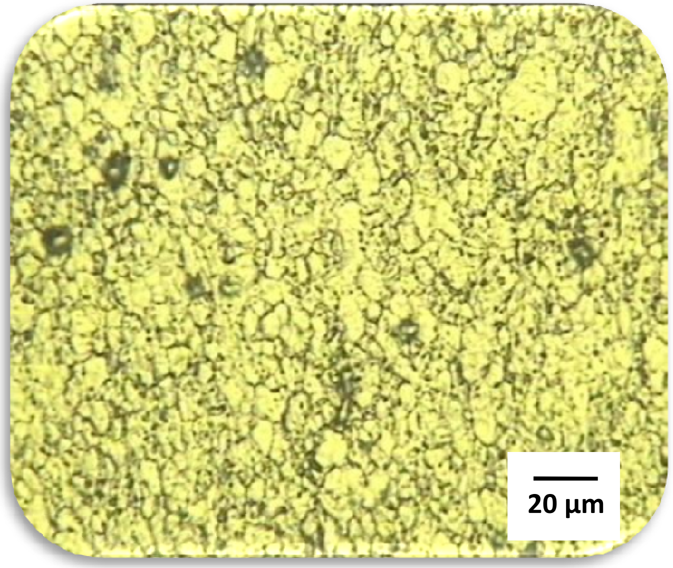
TRANSVERSE TENSILE PROPERTIES OF THE JOINTS

Joint	0.2 % Yield strength (MPa)	Tensile strength (MPa)	Elongation in 50 mm gauge length (%)	Notch tensile strength (MPa)	Notch strength ratio (NSR)
Al alloy (similar)	195	244	15	280	1.15
Mg alloy (similar)	160	200	10	226	1.10
Al/Mg (dissimilar)	90	140	6	125	0.91

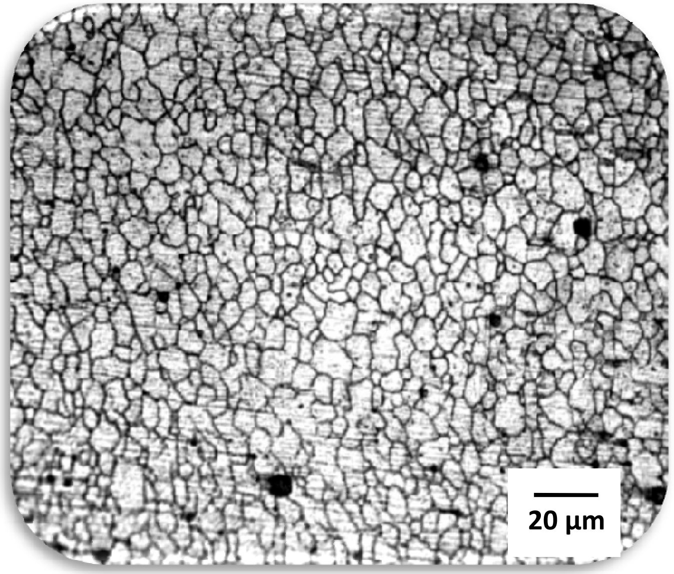
MACROGRAPHS OF THE WELD CROSS-SECTION

JOINT	MACROSTRUCTURE	OBSERVATIONS
AA6061 Al alloy (similar materials joint)		Defect free FSP region; Inverted Trapezoid shaped FSP region; Material mixing and consolidation is uniform
AZ31B Mg alloy (similar materials joint)		Defect free FSP region; Inverted Bell shaped FSP region; Material mixing and consolidation is uniform
AA6061-AZ31B (dissimilar materials joint)		Defect free FSP region; Straight Cylindrical shaped FSP region; Material mixing and consolidation is non-uniform

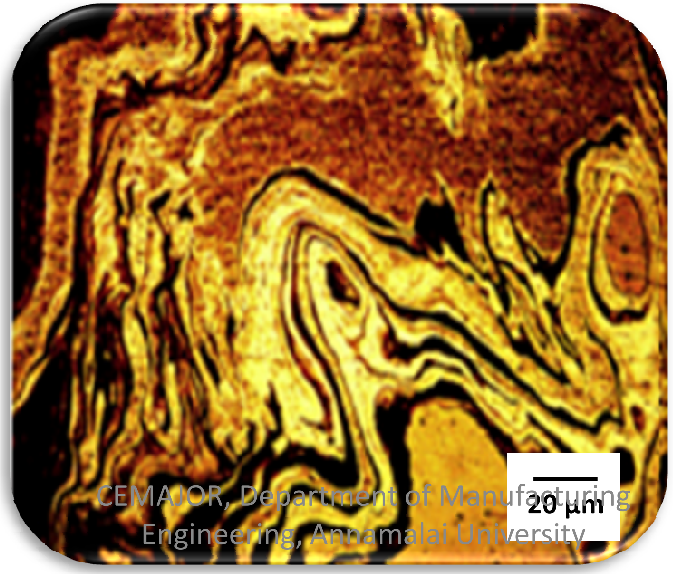
OPTICAL MICROGRAPHS OF MIDDLE REGION OF STIR ZONE



Al ALLOY JOINT

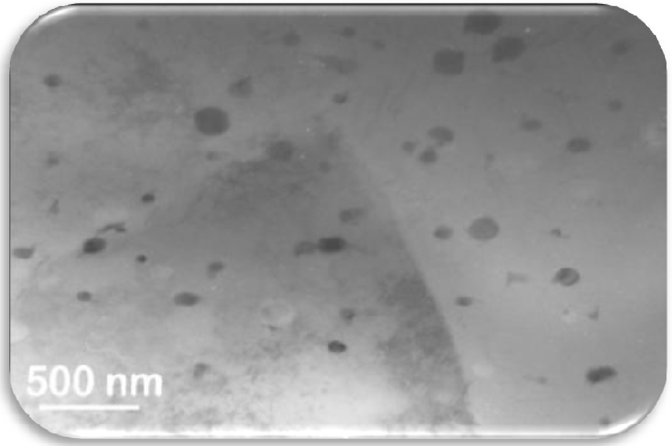


Mg ALLOY JOINT

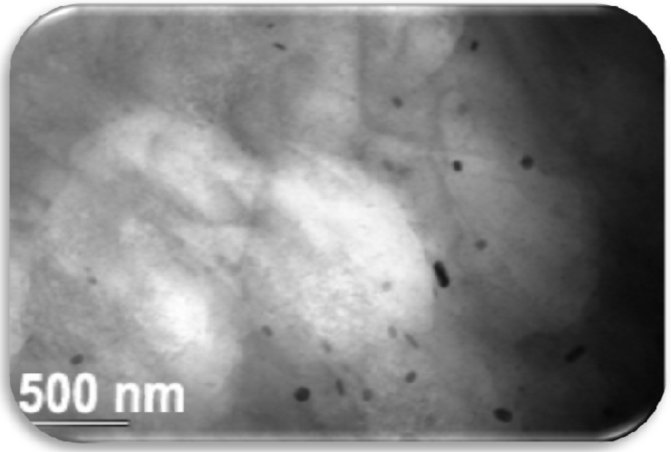


Al/Mg DISSIMILAR JOINT

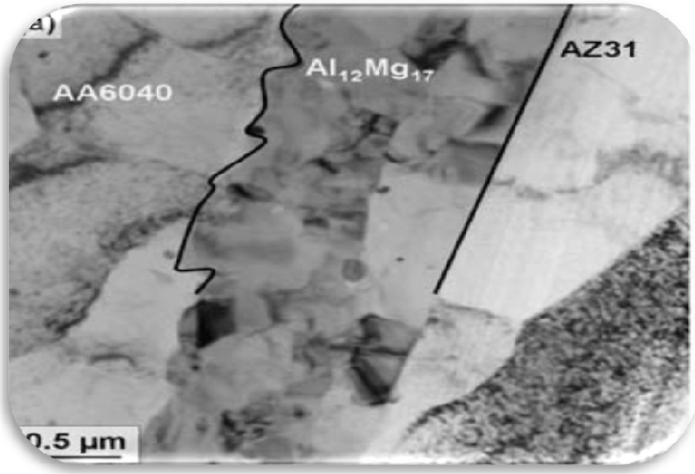
TEM MICROGRAPHS OF STIR ZONE



AL ALLOY JOINT



MG ALLOY JOINT



AL/MG DISSIMILAR JOINT

IMPORTANT FINDINGS

- **The tensile strength of friction stir welded Al/Mg dissimilar joint is 140 MPa which is 40% lower than the friction stir welded Al alloy joint and 30% lower than Mg alloy joint.**
- **Complex intercalated microstructures in the weld zone, with swirls and vortices indicative of the flow pattern of the dissimilar metals. Complex intercalated microstructures in the FSW zone contribute to elevated hardness readings in the weld zone.**

Case Study – 4

WELDING OF TITANIUM ALLOY

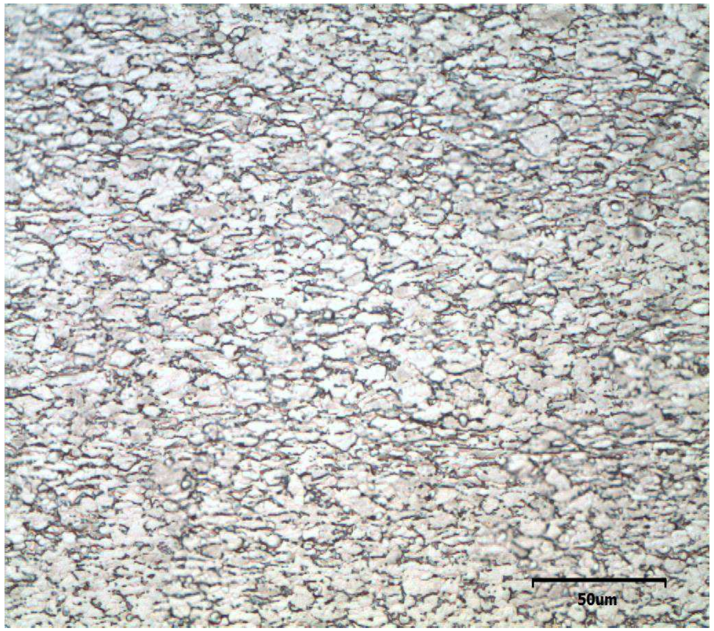
BASE METAL DETAILS

Chemical Composition (wt%)

Ti	Al	V	Fe	C	Si
Bal	6.181	3.745	0.266	0.029	0.025

Mechanical Properties

UTS (MPa)	0.2 % Yield (MPa)	% of Elongation	Micro hardness (HV)
1010	986	22	243



PHOTOGRAPHS OF FABRICATED JOINTS

GTAW

GTCAW

EBW

TENSILE PROPERTIES OF BASE METAL AND WELDED BLE JOINTS

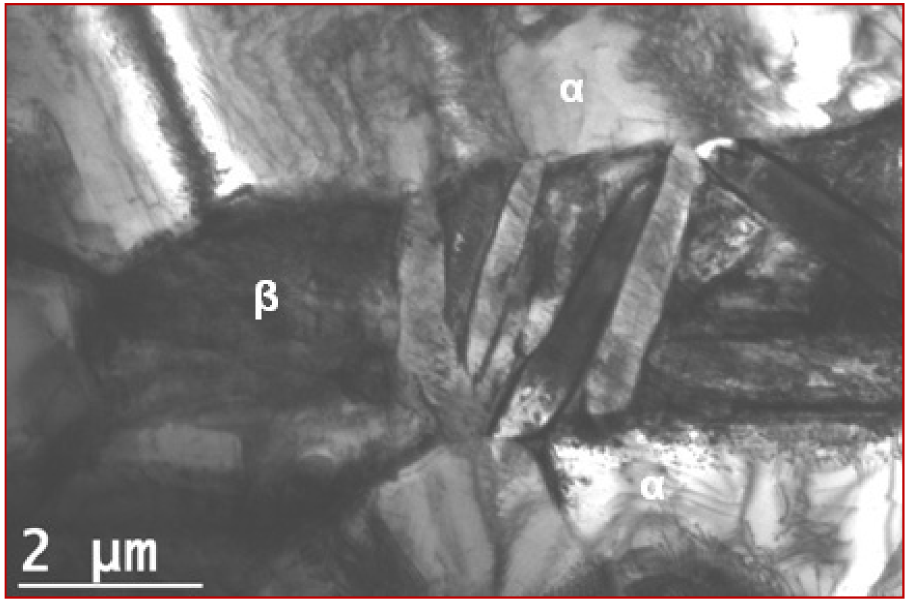
	0.2% YS (MPa)	Tensile strength (MPa)	Elongation (%)	Reduction in c.s.a* (%)	Notch tensile strength (MPa)	Notch strength ratio (NSR)	Impact Toughness @ RT (J)	Joint Efficiency (%)
BM	969	1002	12.7	-	1236	1.23	16	-
GTAW	893	939	10.15	17.48	1047	1.11	15	93.7
GTCAW	960	985	15.00	32.00	1148	1.16	10	98.1
EBW	950	1000	7.70	21.78	1077	1.06	10	99.81

MACROGRAPHS OF WELDED JOINTS. (1,5-UNAFFECTED BASE METAL,2,4-HAZ AND 3-WELD FUSION ZONE)

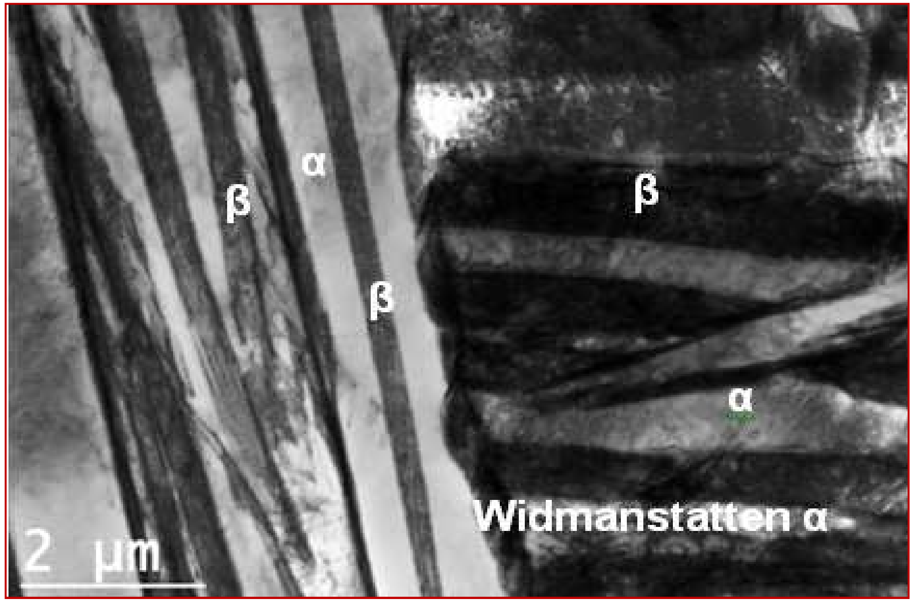
GTAW JOINT

EBW JOINT

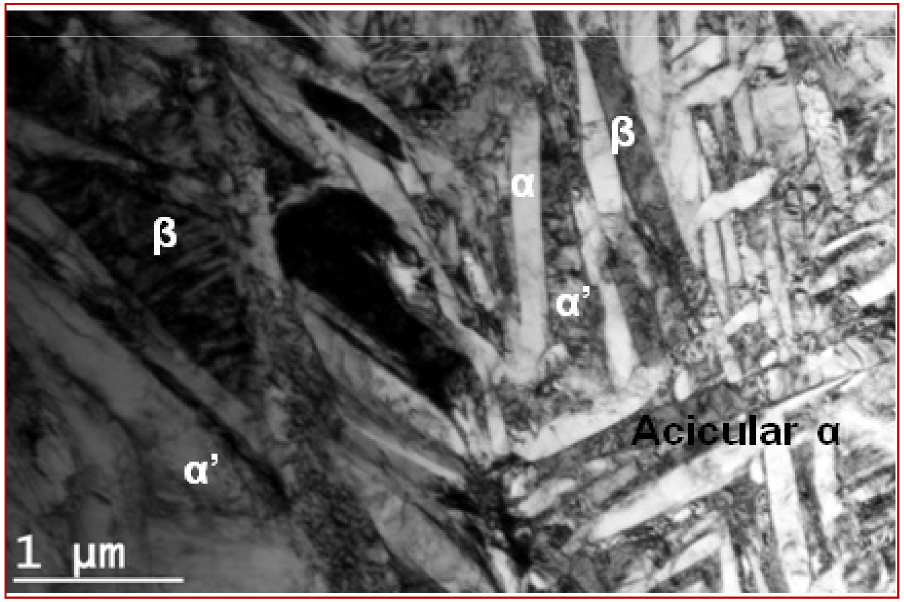
GTCAW JOINT



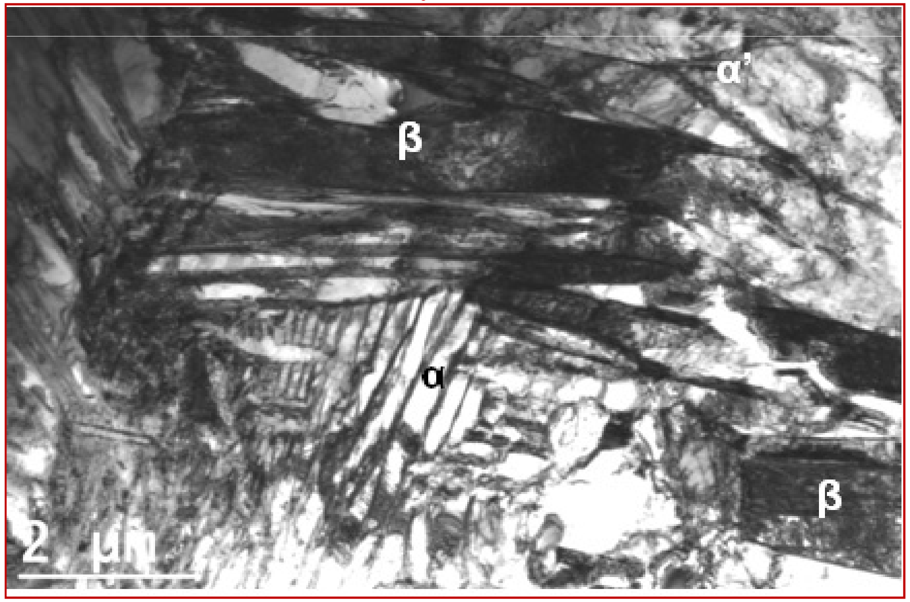
Base metal



GTAW weld metal

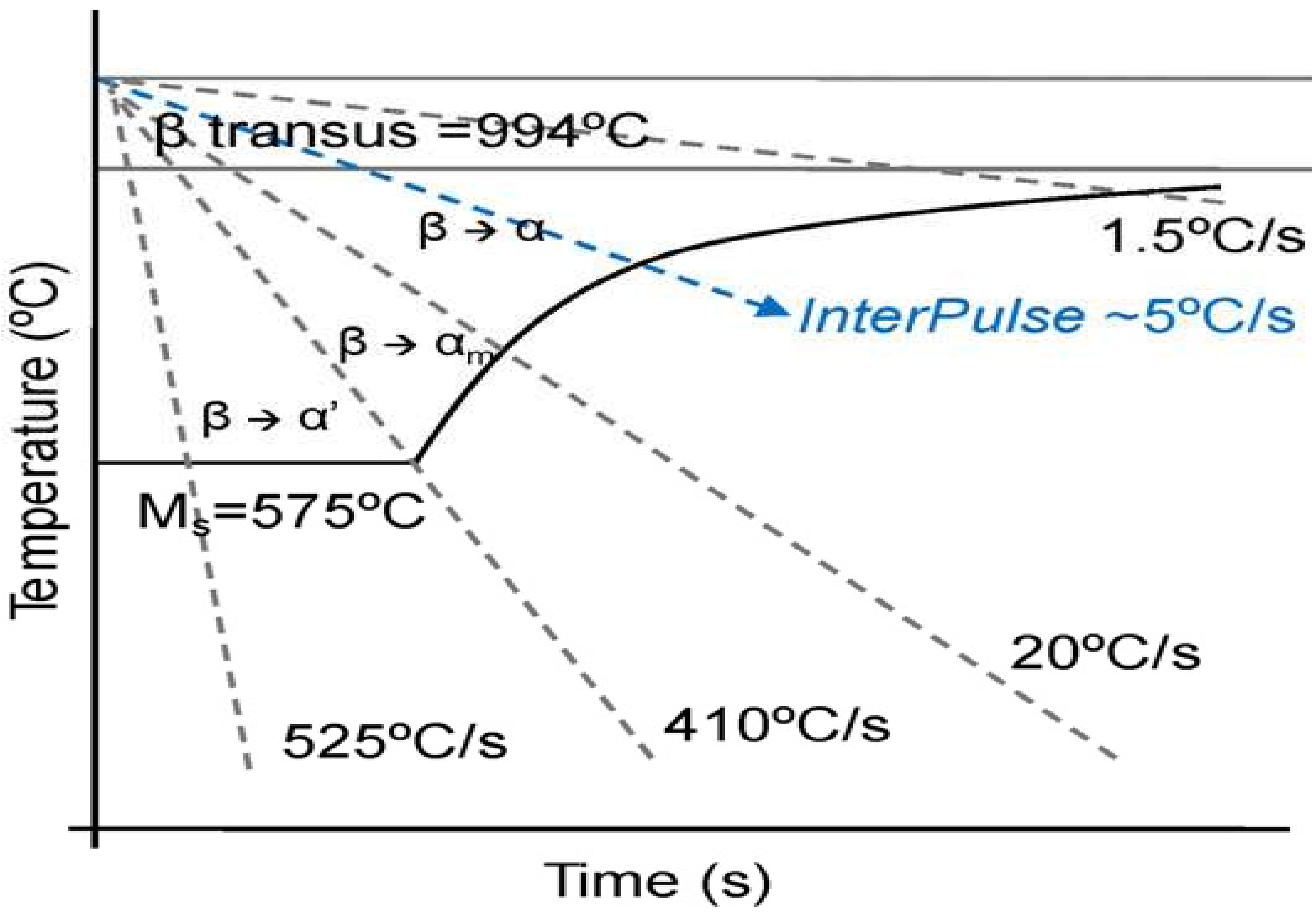


GTCAW weld metal



EBW weld metal

Fig.16 Transmission electron micrographs of base metal and joint's weld metal



β transus =994ºC
β → α
1.5ºC/s
InterPulse ~5ºC/s
β → α_m
β → α'
M_s=575ºC
20ºC/s
410ºC/s
525ºC/s
Temperature (ºC)
Time (s)

RELATIONSHIP BETWEEN COOLING RATE, MICROSTRUCTURAL EVALUATION AND ITS RESULTANT TENSILE, IMPACT TOUGHNESS PROPERTIES.

Sl. No	Processes	Heat input in kJ/mm	Qualitative comparison of Cooling rate	Microstructural feature			Tensile Strength	Impact toughness
				Size of α Colonies	Width of α Lamellae	– GB α Layer		
01	**GTAW**	**1.72**	**Slow**	↑	↑	**Available**	↓	↑
02	**GTCAW**	**0.231**	**Medium**	↓	↓	**Available**	↑	↓
03	**EBW**	**0.146**	**Fast**	↓↓	↓↓	**Available**	↑	↓

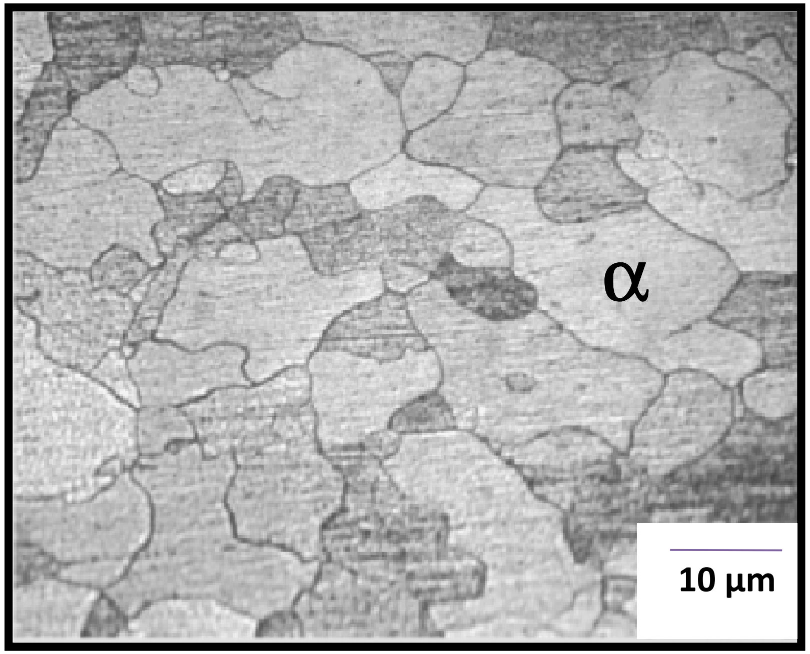
* ↑ - Increases ↓ - Decreases.

Case Study – 5:

WELDING of Interstitial Free (IF) Steel

Chemical composition (mass %) of base metal

Elements	C	Mn	Ti	Al	Si	P	S
BM (IF steel)	0.002	0.08	0.049	0.032	0.004	0.012	0.007



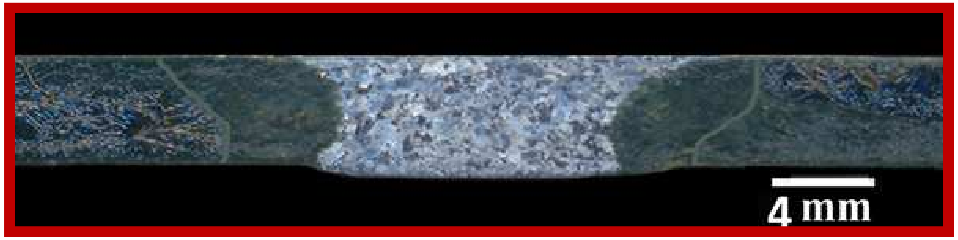
Average grain size = 20 μm

Microstructure of IF steel (As received)

Fabricated GTAW and FSW joints

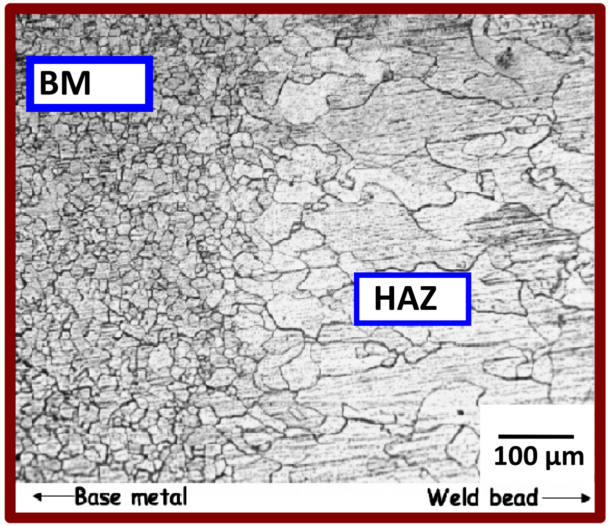
Macrostructure of welded joints

a) FSW

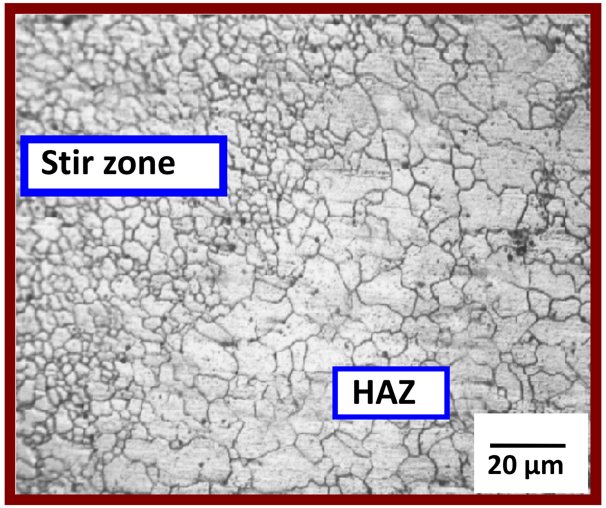


b) GTAW

Optical Micrographs of Welded Joints



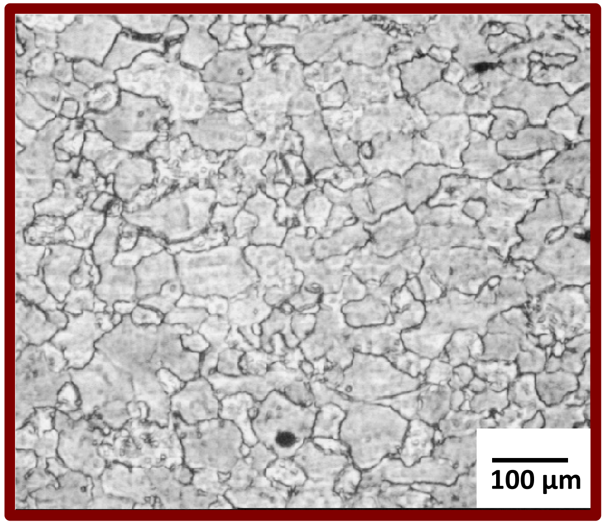
a) GTAW Interface



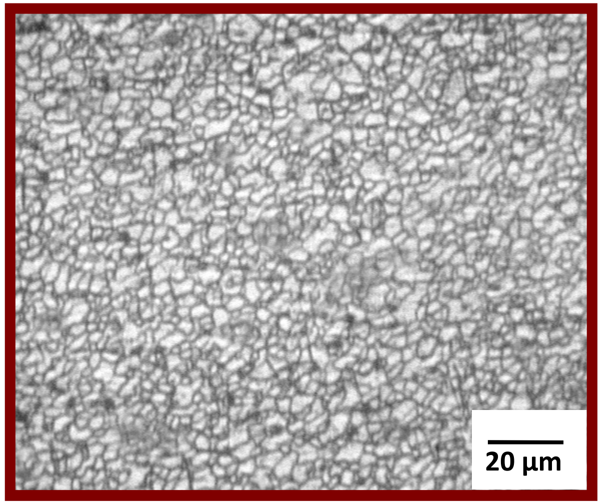
d) FSW Interface

- **Primarily contains coarse grained ferrite microstructure**
- **Due to the grain growth occuring after GTAW process**
- **Both the stirring and extrusion causes the coarser grains to fragment into fine equiaxed grains in the SZ.**

Optical Micrographs of Welded Joints



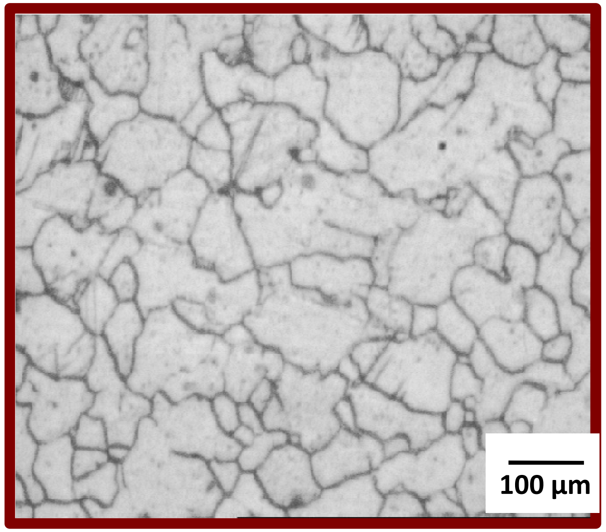
Fusion zone



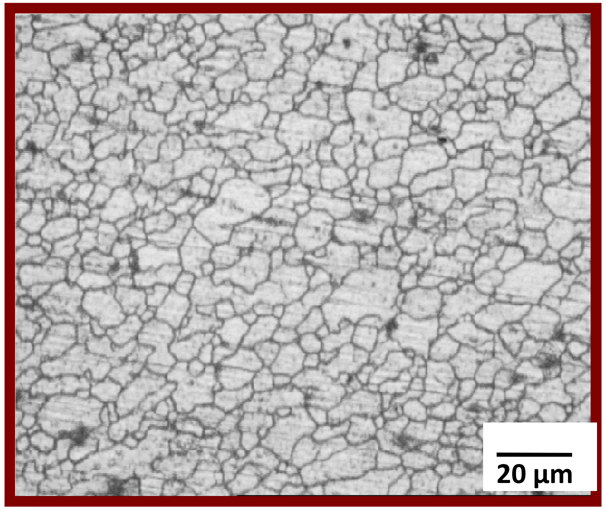
Stir zone

Average grain size	
GTAW-FZ	80 µm
FSW- SZ	5 µm

Optical Micrographs of Welded Joints



c) GTAW- HAZ



f) FSW-HAZ

Average grain size	
GTAW-HAZ	105 µm
FSW- HAZ	20 µm

Traverse tensile properties of IF Steel joints

Joint Type	Yield Strength (MPa)	Ultimate Tensile strength (MPa)	Elongation (%)	Notch Tensile Strength (MPa)	Notch Strength ratio (NSR)	Joint Efficiency (%)
BM	228	282	53	316	1.12	--
GTAW	173	208	22	220	1.06	74
FSW	215	274	40	302	1.10	97

26 % ↓ - by GTAW
3 % ↓ - by FSW
Compared with base metal

24 % ↑ by FSW
Compared to GTAW Joints

Phase 4:

ABOUT MY INSTITUTION

ANNAMALAI UNIVERSITY

- **Unitary, Residential University**
- **Established in 1929 under the Parliament Act**
- **State Government University**
- **Accredited with ‘A’ Grade by National Assessment & Accreditation Council (NAAC), UGC in December 2014**
- **Located at the East Coast, 250 km South of Chennai & 60 km South of Pondicherry**
- **10 Faculties (Arts, Science, Engineering, Agriculture, Medicine, Dentistry, Indian Languages, Fine Arts, Education, Marine Sciences) with 49 Departments spread over 950 acres.**

FACULTY OF ENGINEERING & TECHNOLOGY

- Established in 1945
- Second Engineering college in the Composite state of Madras Province
- Celebrated Diamond Jubilee in 2005
- It has 11 Departments
- Offers 11 UG programs (B.E) and 24 PG programs (M.E)
- All the UG and PG programs are approved by AICTE, New Delhi

Overall Performance of the Department (10 P's)

	Item Description	Numbers		Item Description	Numbers
1.	Publications (a) National Journals (b) International Journals (c) Scopus Indexed Journals	750 150 600 450	6.	Project Grants (in lakhs) (a) R&D Projects (b) I&D Projects (c) Consultancy Projects	1820 1100 600 120
2.	Presentations (a) National Conferences (b) International Conferences	400 250 200	7.	Programs Organized (a) National Events (b) International Events	35 30 05
3.	Ph.D's Produced (a) Full Time (b) Part-Time (Internal) (c) Part-Time (External)	108 25 35 48	8.	Properties (Facilities) (a) Minor Facilities (< 5L) (b) Major Facilities (< 25L) (c) Mega Facilities (>25L)	60 30 20 10
4.	Projects (a) R&D Projects (b) I&D Projects (c) Consultancy Projects	51 35 06 10	9.	Proven Outcome (a) Products (b) Processes (c) Procedures	43 16 12 15
5.	Patents (a) National (b) International	Nil	10.	Partnerships (a) Public Sectors (b) Private Sectors	05 02 03

COURES OFFERED BY THE DEPT.

1) B.E MECHANICAL (MANUFACTURING)
2) M.E (MANUFACTURING ENGINEERING)
3) M.E (NANO MATERIALS & SURFACE ENGINEERING) under UGC Innovative Program Scheme
4) M.E (WELDING ENGINEERING) with Industry Partnership
5) Ph.D (MANUFACTURING ENGINEERING)

CURRENT THRUST AREAS OF RESEARCH

- Materials Joining
- Surface Engineering
- Synthesis of Newer Materials
- Materials Processing
- Manufacturing Management

Centre for Materials Joining & Research (CEMAJOR)

- Established under AICTE -NAFETIC (National Facilities in Engineering Technology with Industrial Collaborations) scheme in 2006.
- A 3 storey building with 10 Laboratories under one roof
  - Fusion Welding Laboratory
  - Solid State Welding Laboratory
  - Plasma Processing Laboratory
  - Physical Metallurgy Laboratory
  - Mechanical Testing Laboratory
  - Corrosion Testing Laboratory
  - Tribology Laboratory
  - Modelling & Simulation Laboratory
  - Thermal Spray Laboratory
  - High Temperature Laboratory
- Centre has completed 35 R&D projects worth of Rs. 900 lakhs
- Centre has 5 on-going R&D projects worth Rs.300 lakhs

SPONSORED R&D PROJECTS COMPLETED

No.	Name of the Funding Agency	Number of R&D Projects	Grants Received (in Rs. Lakhs)
1.	All India Council for Technical Education (AICTE), New Delhi	2	20.75
2.	University Grants Commission (UGC), New Delhi	4	43.50
3.	Department of Science & Technology (DST), New Delhi	7	158.00
4.	Aeronautical Research & Development Board (ARDB), DRDO	2	41.00
5.	Armament Research Board (ARMREB), DRDO	2	30.50
6.	Naval Research Board (NRB), DRDO	2	61.85
7.	Extramural Research & Intellectual Property Rights (ERIPR), DRDO	4	145.00
8.	Board of Research in Nuclear Sciences (BRNS), DAE	3	25.00
9.	Ministry of Environment & Forests (MoEF), New Delhi	2	235.00
10.	Aeronautical Development Agency (ADA)	1	12.00
11.	Council of Scientific Industrial Research (CSIR), New Delhi	1	24.00
12.	CARS Projects (through DRDO Labs)	5	50.00
	TOTAL	35	846.60

MAJOR FACILITIES IN MATERIALS JOINING

- 400 A Pulsed Current TIG Welding Machine
- 400A Pulsed Current MIG Welding Machine
- Welding Chamber with Ozone Analyser
- 2T Friction Welding Machine
- 1000° C Diffusion Bonding Machine
- Electrical Resistance Spot Welder
- 1.2 T Friction Stir Welding Machine (Manual)
- 6T Friction Stir Welding Machine (CNC)
- 1600 ° C Diffusion Bonding Machine
- 600 W Nd-YAG Pulsed Laser with ABB Robot
- Linear Friction Welding Machine
- Cold Metal Transfer (CMT) Welding Machine
- Inter Pulse TIG Welding Machine
- Ultrasonic Welding Machine
- Plasma Arc Welding (Micro & Keyhole) Machine

MAJOR FACILITIES IN MATERIALS JOINING


PTAW


TIG Welding


MIG Welding


MAO


FW Machine


DB Machine


FSW (Manual)


FSW (CNC)


HTDB


Implant Testing


Ozone Analyser


RSW Machine


MAO


LFW Machine


LBW

MAJOR FACILITIES IN SURFACE ENGINEERING

- 40 kW Atmospheric Plasma Spraying Machine
- High Velocity Oxy Fuel Spraying Machine
- Powder Flame Spraying Machine
- Wire Arc Spraying Machine
- 500 W Nd-YAG Laser Surfacing System
- Physical Vapour Deposition (PVD)
- Chemical Vapour Deposition (CVD)
- Gill AC Potentiostat
- Salt Spray Tester
- Erosion-Corrosion Tester
- Pin-on-Disc Wear Tester
- Air Jet Erosion Tester
- Dry Abrasion Tester
- Water jet Erosion Tester
- Slurry Erosion Tester
- Thermal Cycling Furnace
- Micro Arc Oxidation Coating Machine
- Scratch Hardness Tester

MAJOR FACILITIES IN SURFACE ENGINEERING


APS System


Laser Surfacing


HVOF Spray


Flame Spray


TWA Spray


PVD


CVD


Tubular Furnace


TCF Machine


HT Dilatometer


Slurry Erosion


POD Wear Tester


Air Jet Erosion Tester


DAT


WJET


Gill AC PC Tester


POR Wear Tester


Microwave Furnace


Ball Mill Machine


SB Unit

MAJOR FACILITIES IN NEWER MATERIALS

- 1600 deg C Tubular Sintering Furnace
- 1400 deg C Microwave Furnace
- Bottom Pouring Stir Casting Furnace
- Transferred Arc Plasma (TAP) melting Furnace
- Electron – Beam Physical Vapour Deposition (EB-PVD) Machine
- DC/RF Sputtering Machine
- High Energy Ball Mill
- 1400 C Dilatometer

MAJOR FACILITIES IN NEWER MATERIALS

TUBULAR SINTERING FURNACE

MICROWAVE FURNACE

TAP MELTING FURNACE

PVD

CVD

BALL MILL

GENERAL FACILITIES


UTM


UTM-HT Testing


Dynamic Tester


Hydraulic Tester


CTM


EDM


ECM


MHT


Optical Microscope


SHIMADZU MHT


Tensometer


RBFM


Ultrasonic FD


AER


SEM

PHASE 5:

QUESTION AND ANSWER SESSION

Please feel free to contact me

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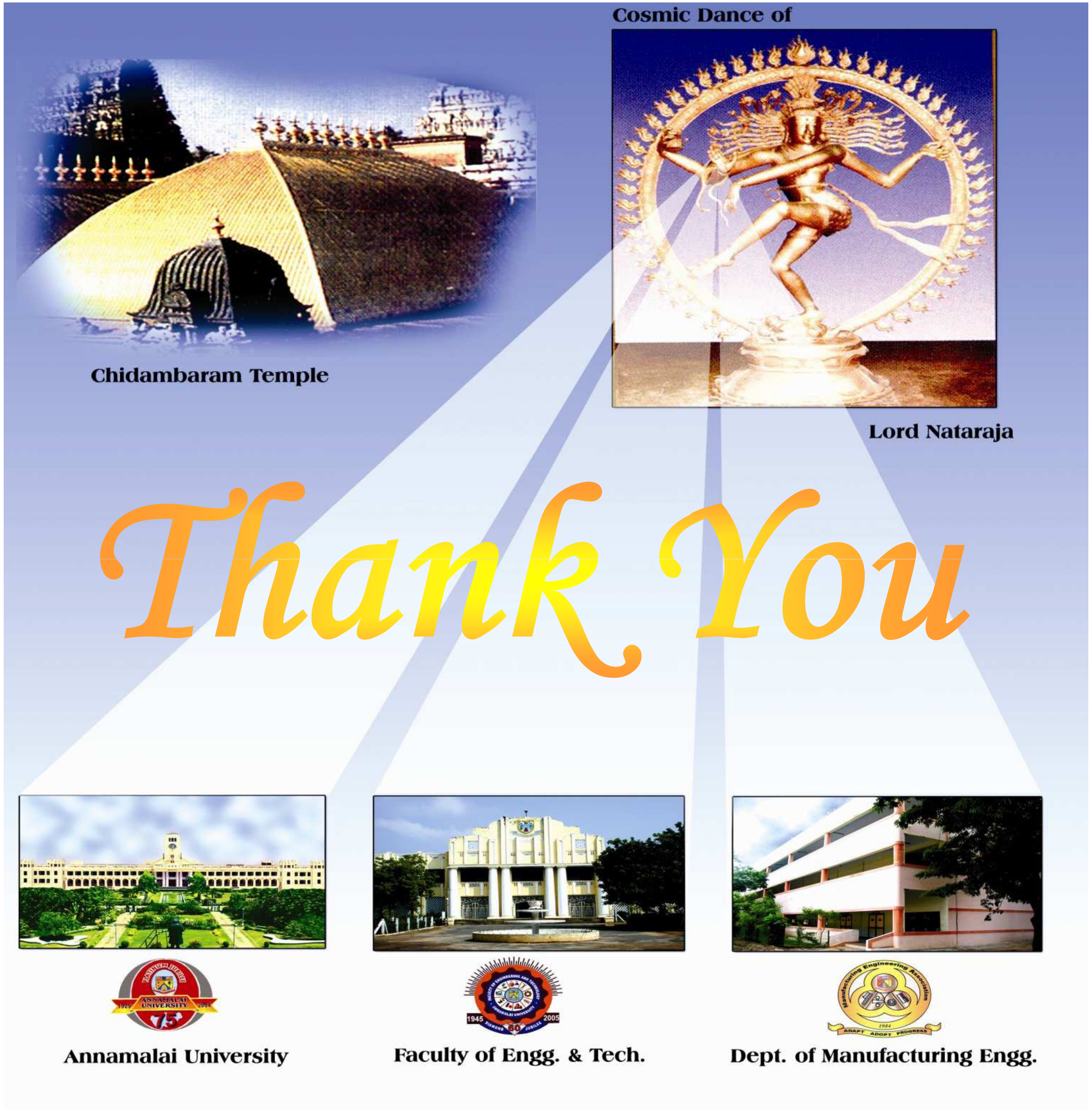
- Email: visvabalu@yahoo.com
- Website: www.annamalaiuniversity.ac.in


Cosmic Dance of
Lord Nataraja
Chidambaram Temple
Thank You
Annamalai University
Faculty of Engg. & Tech.
Dept. of Manufacturing Engg.