

Friction Stir Welding

Module: M6X00414

Rachel Alexander and Greg Owen

Traditional Welding Processes

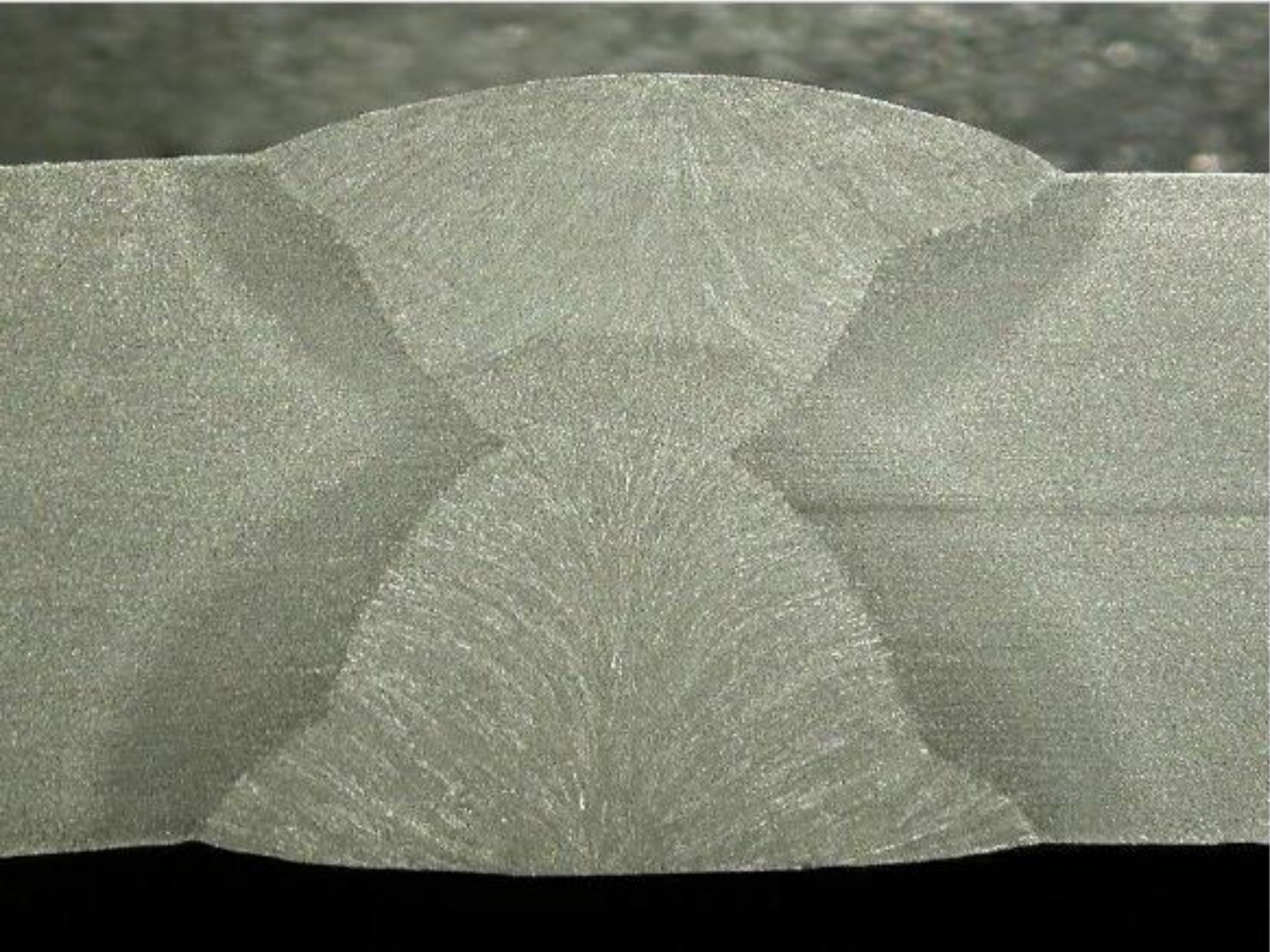
Fusion welding: In this process, base metal is melted by means of heat. Often, in fusion welding operations, a filler metal is added to the molten pool to facilitate the process and provide bulk and strength to the joint. Commonly used fusion welding processes are: arc welding, resistance welding, oxyfuel welding, electron beam welding and laser beam welding.

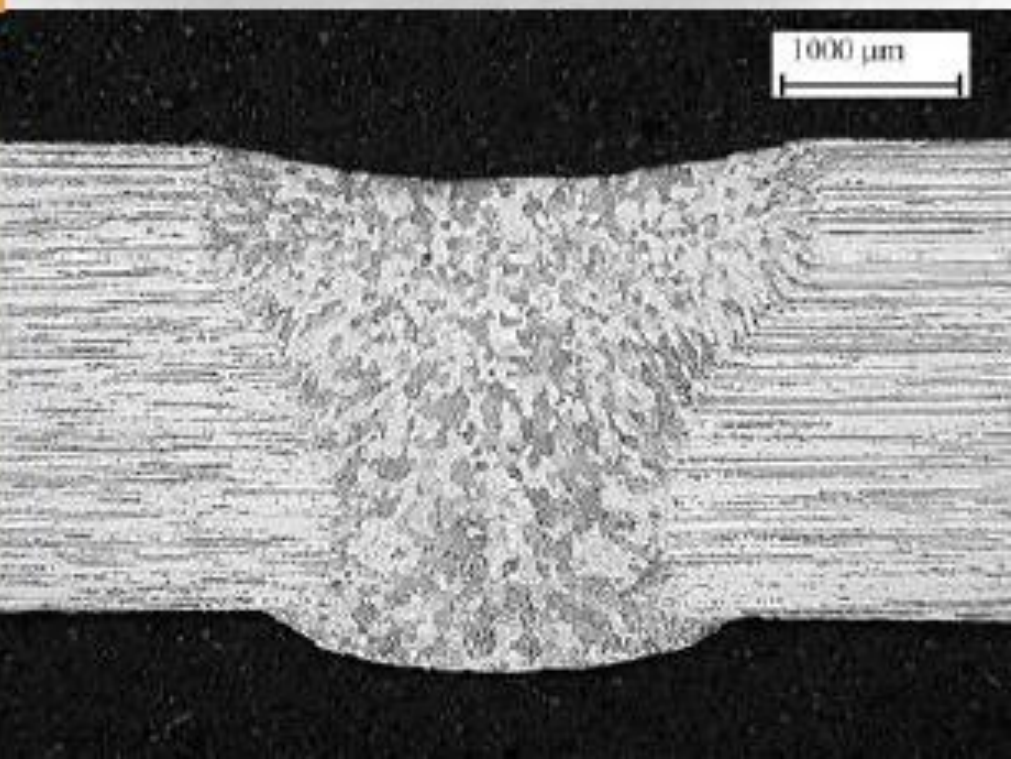
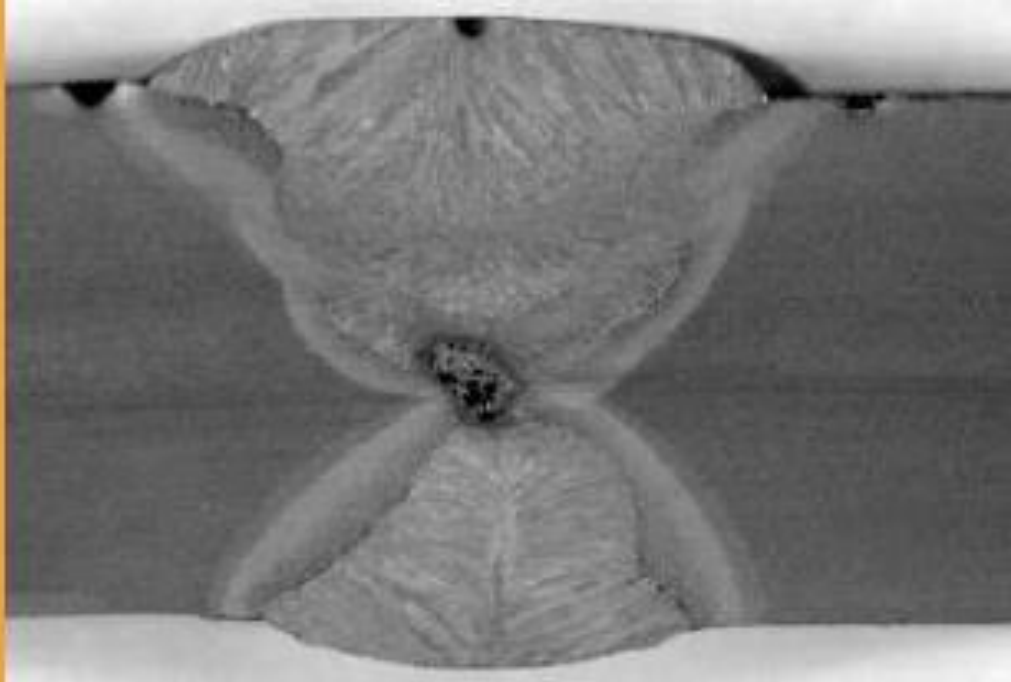
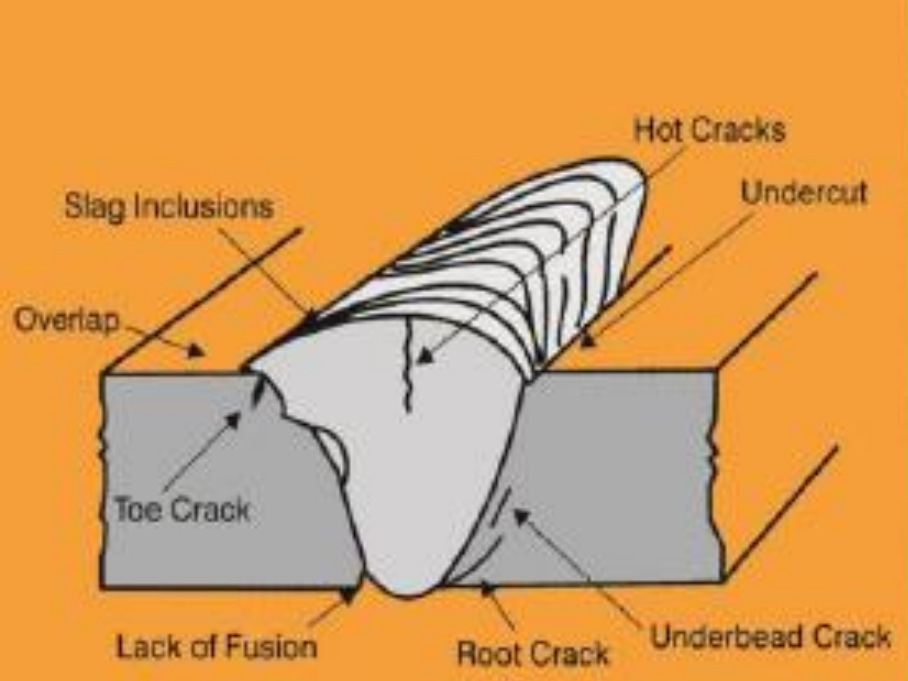
Pictures courtesy of TWI

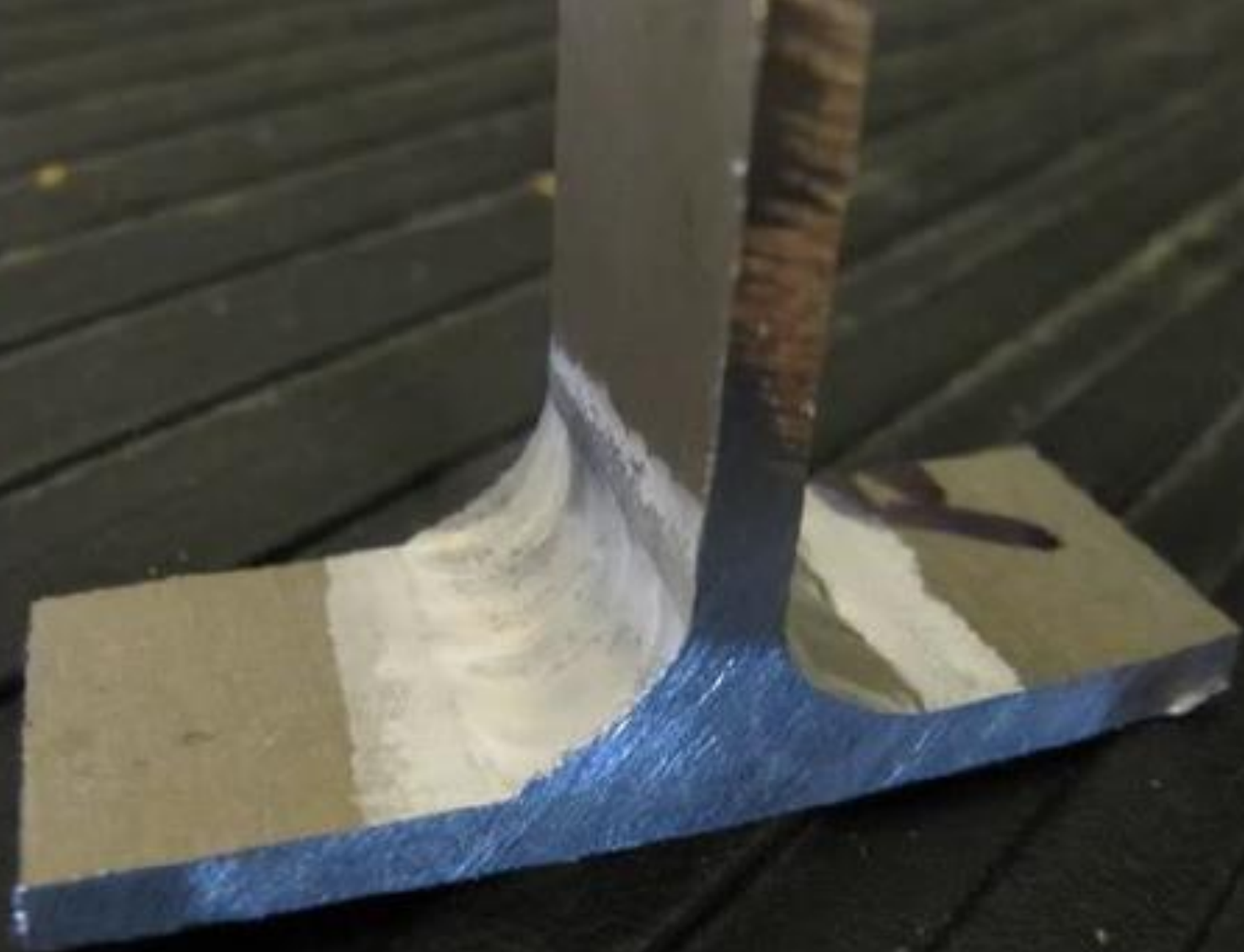




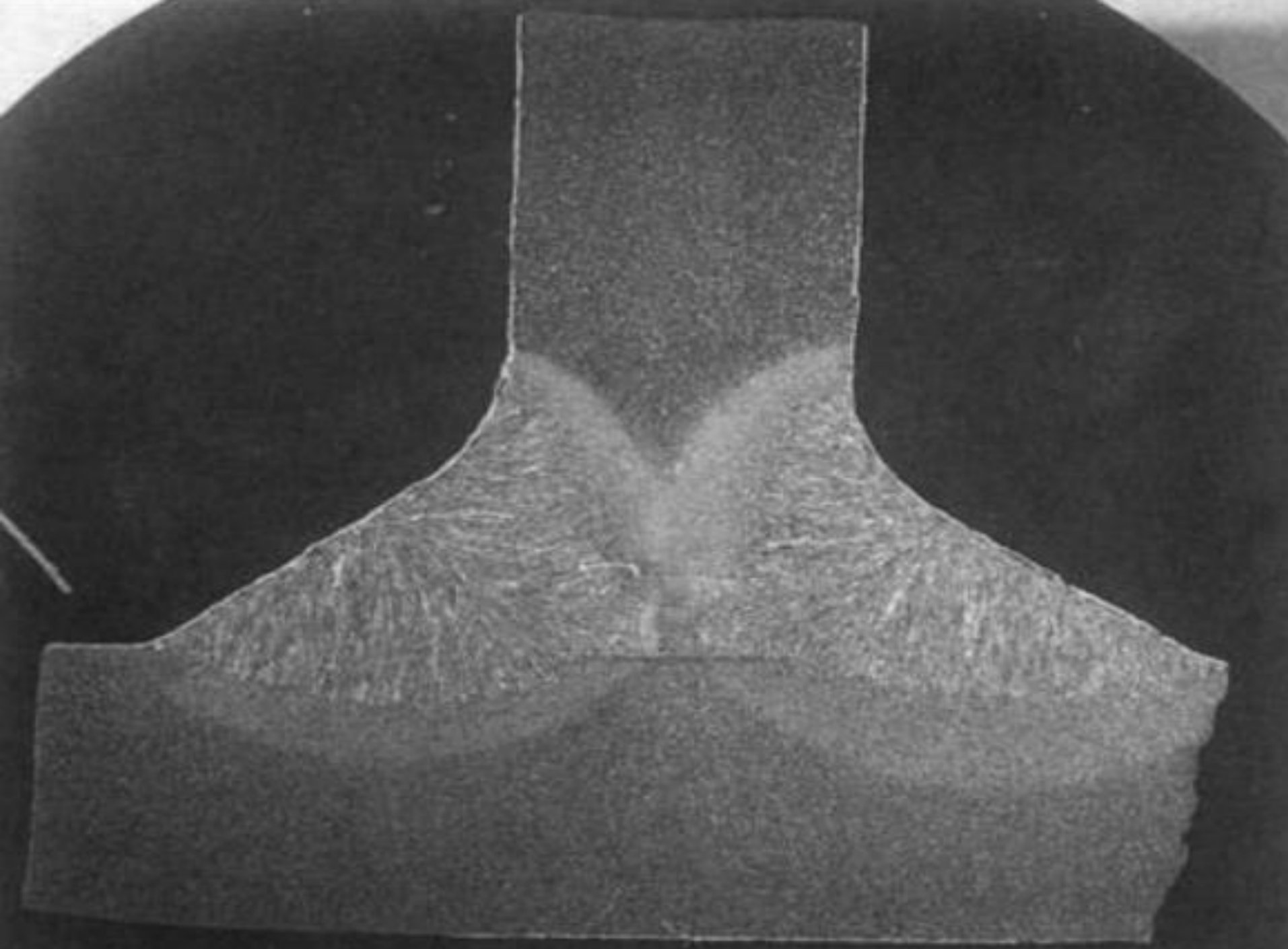


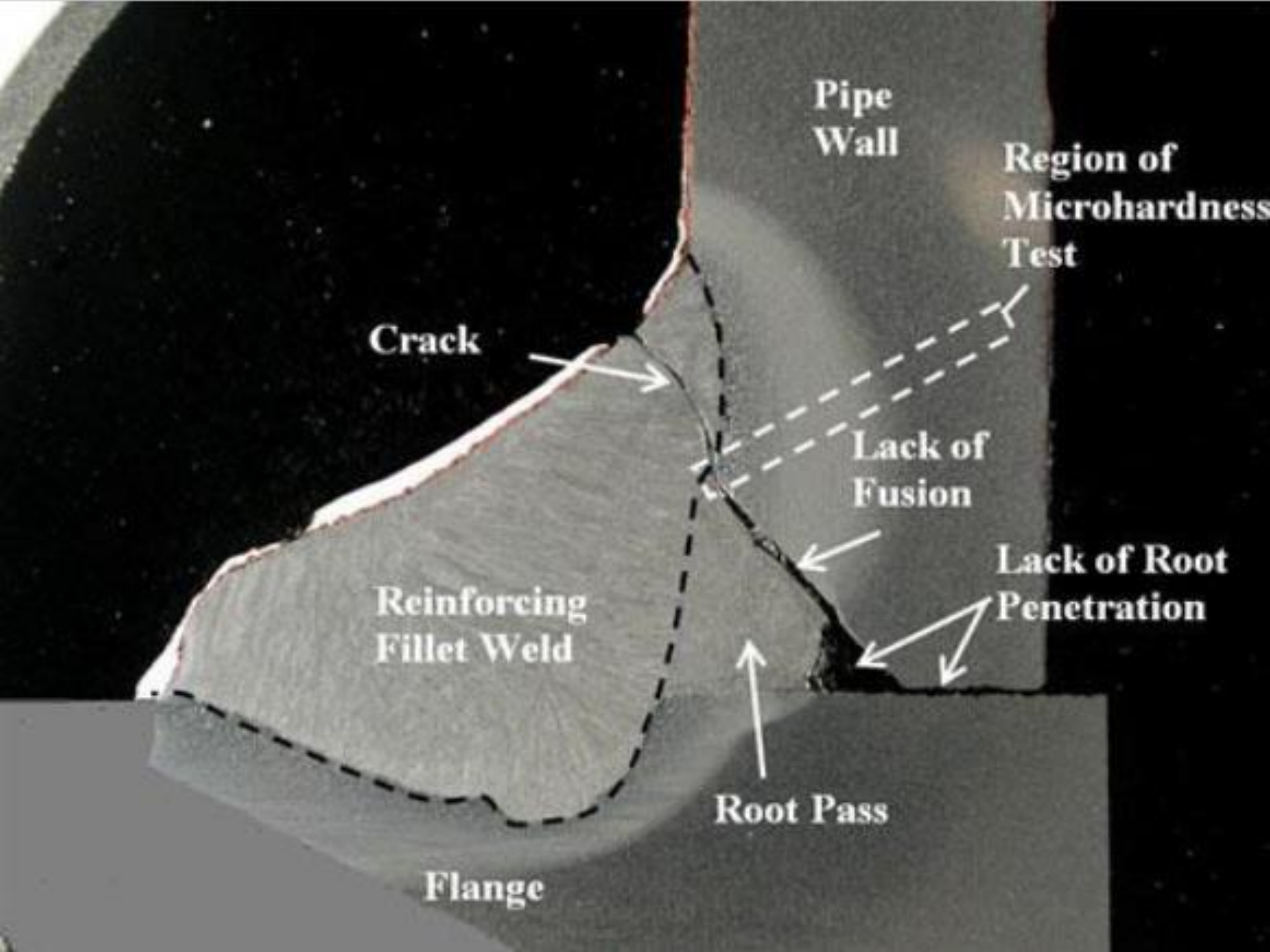


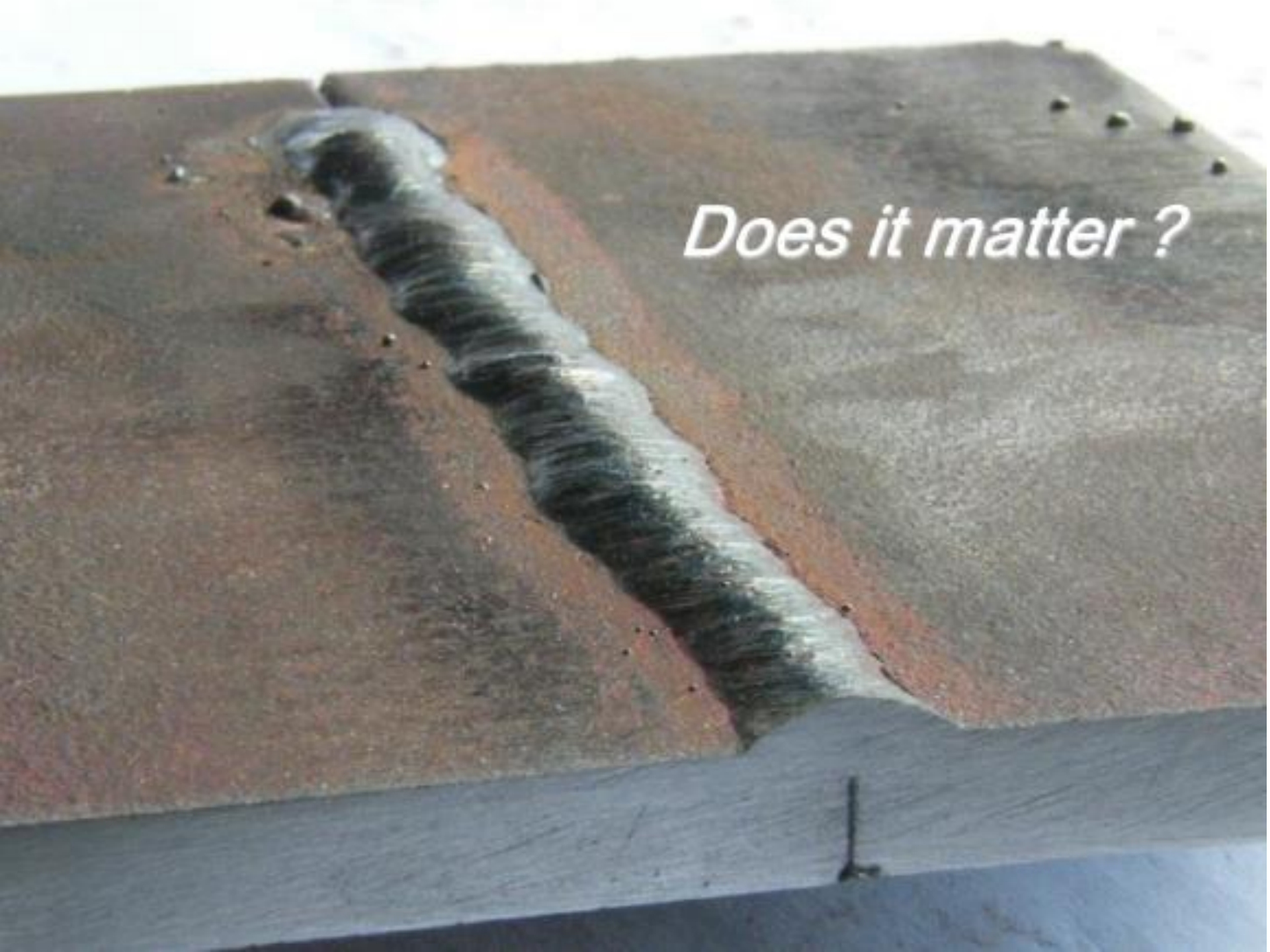












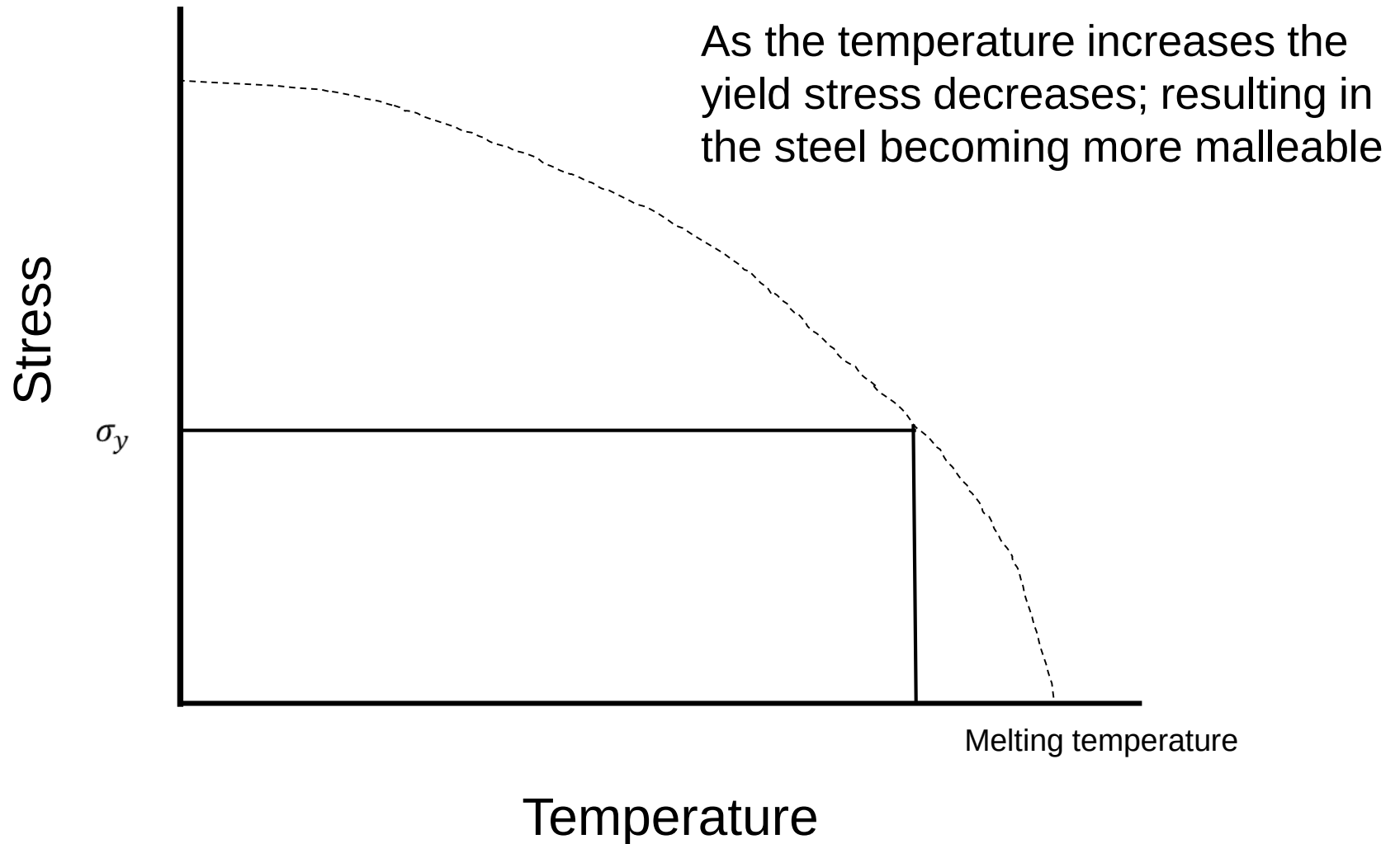
Does it matter ?



Consider forging, this is done by heating up a piece of steel to the point where it becomes bright red and can be hammered to deform its shape. The metal is not liquid at this stage but it is in a plastic state, a similar process is observed with friction stir welding.



Solid State Welding

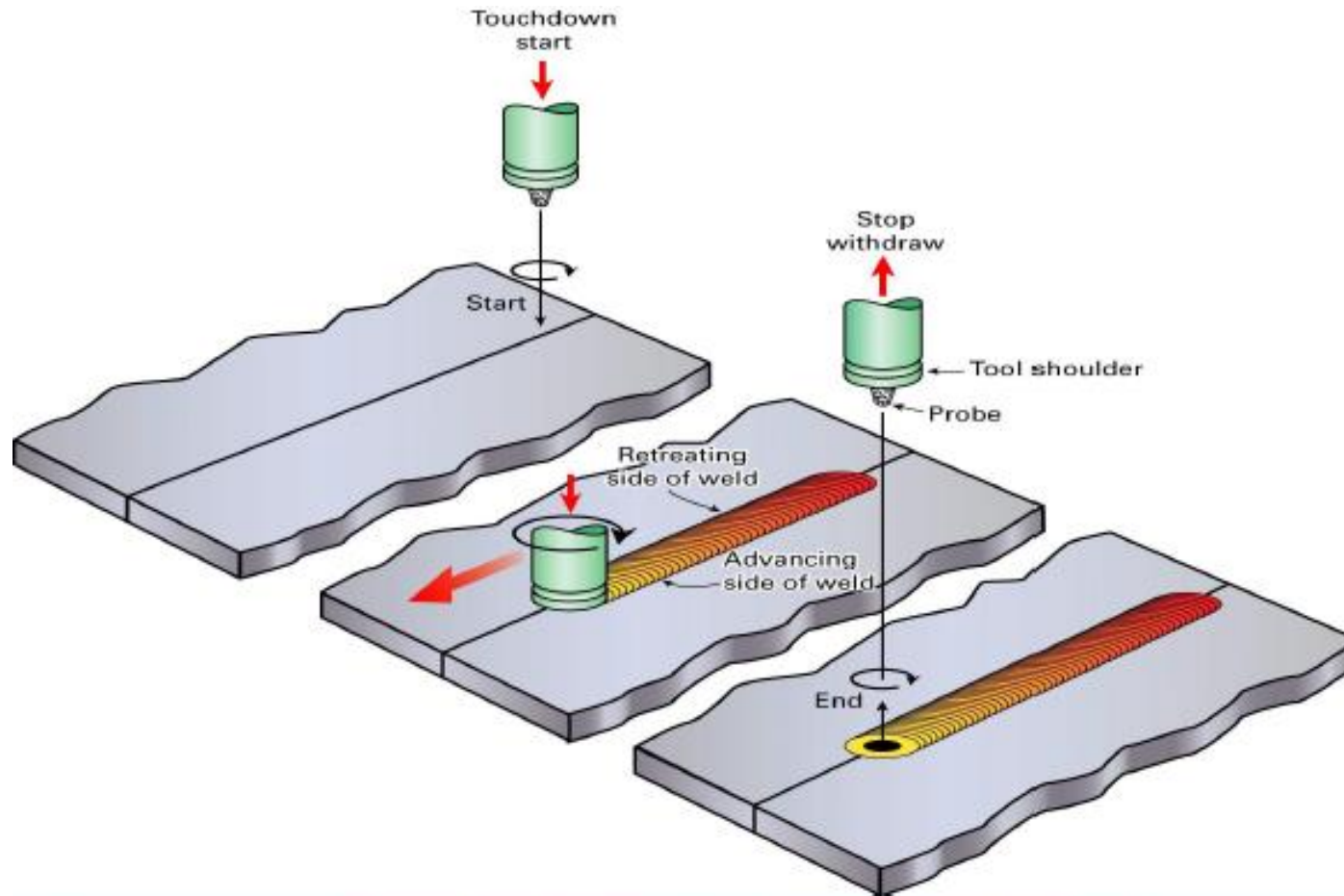


Friction Stir Welding (FSW)

The Process:

- Combined action of frictional heating and mechanical deformation due to a rotating tool
- A cylindrical shouldered joint with a profiled pin is inserted into the joint line
- Heat is generated by friction between a rotating-translating tool and the shoulder of which rubs against the work piece
- Plates are firmly clamped with a backing bar below the weld line

Friction Stir Welding (FSW)



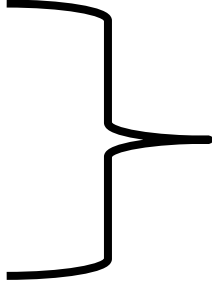
Parameters which control FSW

- Downward force
- RPM
- Transverse force
- The material which the tool shoulder is made from (*thermal conductivity considerations, frictional characteristics should be as high as possible etc*)

Parameters which control FSW

- The pin is forced into the plates at the joint until the shoulder contacts the plate surface
- A downward forging pressure from the shoulder helps to prevent the expulsion of softened material
- This also provides additional friction
- Plasticises a cylindrical metal column around the pin and the immediate material under the shoulder
- As the tool moves forward, material is forced to flow from the leading edge to the trailing edge of the tool
- The material that flows around the tool undergoes extreme levels of plastic deformation

Parameters which control FSW

- Significant benefits of FSW are that there are only three variables which need to be controlled:
 - Tool rotation
 - Travel speed
 - Pressure

For a given type of tool geometry
- There is a unique combination of shear and normal forces in FSW.

Advantages over arc welding

- High quality weld can be achieved
 - with absence of solidification cracking
 - Porosity
 - Oxidation – *no shielding required*
 - Other defects resulting from traditional fusion welding
- Low apparent energy inputs of FSW
 - Less distortion and residual stress



Tool Geometry

- Optimum tool design will produce the desired joint quality as well as enabling a higher welding speed and longer tool life
- The shape of the bottom of the tool shoulder affects the material flow around the tool nib.
 - Can be flat or concave
 - Smooth or grooved with concentric or spiral grooves



- A concave shoulder has an advantage compared with a flat bottom
 - Directing material flow to the centre, close to the nib
- The tool nib has a diameter which is about one-third of the tool shoulder and typically has a length slightly less than the thickness of the work piece.



Mass Flow

- Mass flow around the tool is very complex.
- Correct mass flow is essential in optimising process.
- Usually necessary to move material up and down
- The mass flow is highly asymmetric, with almost all material passing down retreating side of tool.
- Mass flow can be modelled using computational fluid dynamics and other methods.
- Substantial research effort in many laboratories to improve modelling.

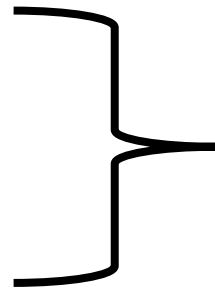
Skew-stir technique

- An orbital motion of the tool is achieved by inclining the longitudinal axis of the tool with respect to the retaining machine spindle
- Increases the ratio of the 'swept' volume to the physical volume of the tool
 - Referred to as the dynamic to static volume ratio
- This parameter has a significant effect towards achieving the required level of both weld quality and process efficiency



Parameters which control FSW

- Downward force
- RPM
- Transverse force



Responsible
for heat
generation



Tool shoulder material and backing material

- The tool shoulder material plays an important role in the heat generation process of FSW
- Compared to tool steel, the shoulder made from Zirconia engineering ceramic seems to generate approximately 30-70% more heat depending on the welding parameters
- The welding efficiency is affected by the heat loss through the tool as the steel backing bars



- Using a tool material with a low thermal conductivity along with a suitable non-conducting backing bar.
 - This will enable increasing welding speed
 - An increase in welding speed necessitates a similar increase in rotational speed to get sound welds



Heat generation

- Heat generation in FSW process increases with increasing tool rotation speed and tool downward force
- Travel speed influences
 - Rate of heat input
 - Affecting metal flow around the tool nib
- Other relevant parameters are
 - Shoulder radius
 - Shoulder angle of the FSW tool
 - Time of indentation of the tool



Heat Flow

- Important to understand heat flow.
- Simple Rosenthal solutions give good far-field predictions, not so good close to weld.
- Heat flow close to tool complicated by mass flow, which also transports heat.
- Accurate heat flow essential in predicting mechanical properties, tool forces etc.

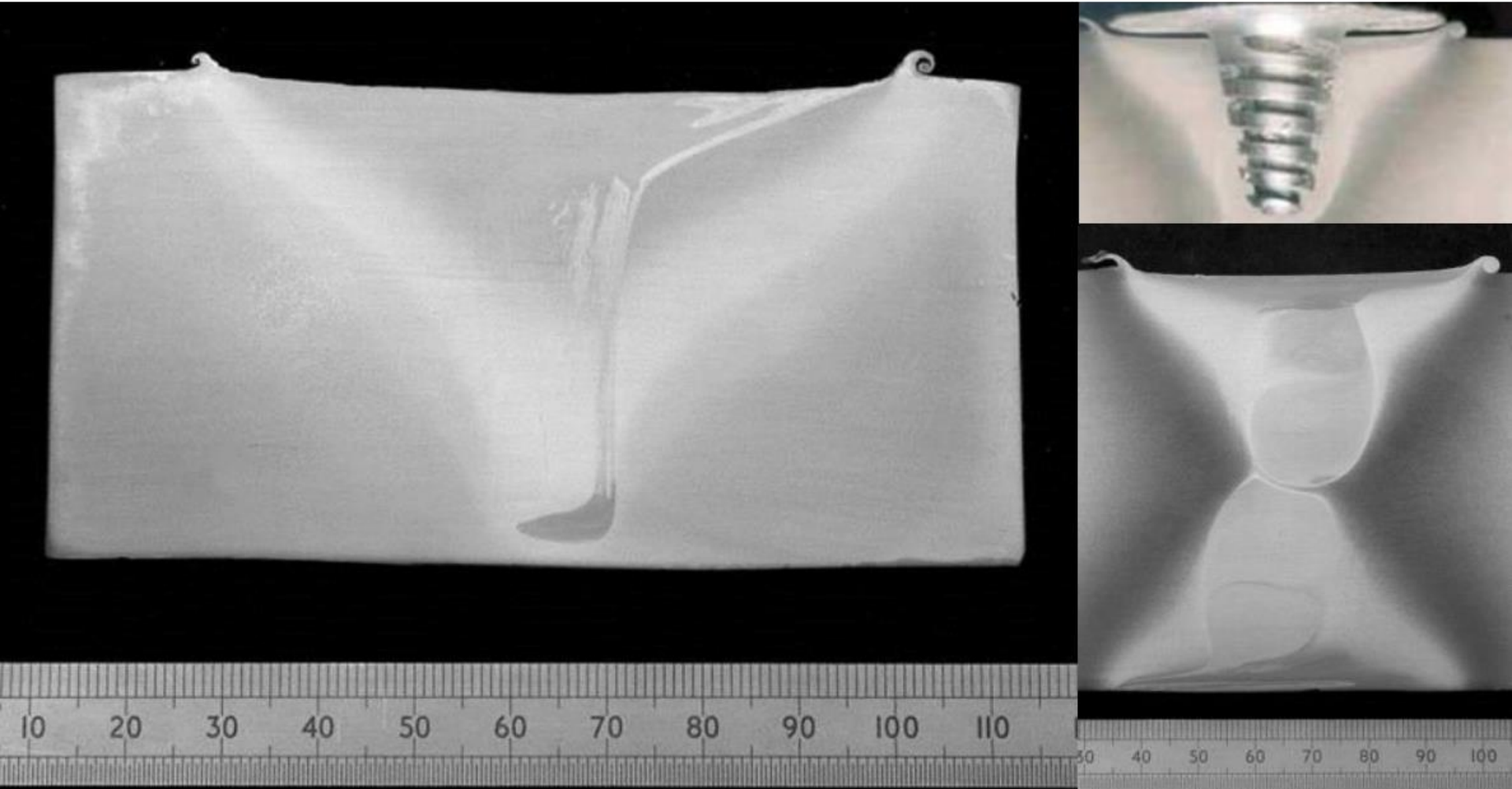
- Time of indentation of the tool
 - The period between the instant the tool contacts the work-piece and the instant the tool begins moving along the joint
 - Can range from 5s to 30s
- During this period, generated heat spreads in the vicinity of the tool nib softening the adjacent material and stabilising material flow around the tool nib



- If this period is too short
 - Defects can appear in the initial part of the weld
- The tool shoulder angle allows a gradual increase of the pressure on the top surface of the plates.
 - Defects can appear in the initial part of the weld
- Tool angles up to 30° are common



Friction Stir Welding



Heat transfer into the tool and work piece

- The amount of heat conducted into the work piece determines the quality of the weld, residual stress and distortion of the work piece
- The amount of heat that flows to the tool dictates the life of the tool and the capacity of the tool for the joining process
- Insufficient heat from friction could lead to breakage of the tool nib since **this period is too short**
 - Defects can appear in the initial part of the weld
 - the material is not soft enough



- Depending on the thermal conductivity of the tool material, about 95% of the heat is transferred into the work piece and only 5% flows into the tool
- The maximum temperature created by FSW process ranges from 80% to 90% of the melting temperature of the material being welded.



Heat generation can be considered using friction laws and Rosenthal equations.

- Substitution of typical values into these equations would show that in most cases the majority of the heat is generated by the occurrence of shear between adjacent layers of workpiece material.
- Adjacent vertical layers of material will move different distances in a given time, therefore generating shear processes between them. This is known as adiabatic shear.

Heat input is important!

- Determines width of heat affected zone (HAZ)
- Determines minimum strength in weld region
- Influences other performance criteria, e.g. corrosion resistance, grain size, formability, etc.
- Useful to compare FSW with other processes
- Can be easily calculated in a well instrumented system

Calculation of linear heat input

Heat input (HI) = power/travel speed

Power (P) = torque (T) x angular velocity (ω)

$$P = 2\pi rT/60 \text{ (J/sec)}$$

$$HI = 2\pi rT\varepsilon/1000v \text{ (kJ/mm)}$$

r = spindle rotation speed (rev/min)

T = spindle torque (Nm)

ε = efficiency factor

v = travel speed (mm/min)

The forward movement per revolution is calculated simply as:

$$F = v/r$$

Where F = forward movement per revolution (mm/rev)

v = traversing speed (mm/min)

r = rotation speed (rev/min)

This ratio appears in the Heat Input equation

Summary

- FSW is a solid state process, related to milling in its operation, but closely allied to extrusion.
- Heat generation is complex, but modelling and experimental work have provided considerable insight
- Mass flow is very complex, but again modelling can improve our understanding
- We are still learning about the fundamentals, and there is still a long way to go!

ISO 25239:1 defines the accepted vocabulary for FSW.
The most important terms are:

- ▣ **Advancing side**: the side of the weld where the tool rotation is the same as the welding direction
- ▣ **Axial force**: the force applied along the axis of tool rotation (the downward, or forging force, F_z)
- ▣ **Exit hole**: the hole remaining after the tool is withdrawn
- ▣ **Force Control** – method of maintaining the required force in welding
- ▣ **Heat Affected Zone** – area of weld that is heated but not stirred
- ▣ **Heel**: the part of the tool shoulder at the rear relative to the forward motion of the tool
- ▣ **Position control**: method of maintaining the tool position in welding

Vocabulary of FSW

- **Pin / Probe**: that part of the tool embedded in the workpiece
- **Retreating side**: the side of the weld where the direction of tool rotation is opposite to the direction of welding
- **Shoulder**: that part of the tool in contact with the surface of the workpiece material
- **Stirred Zone**: region in the welded zone where a fine grained equi-axed microstructure exists
- **Thermomechanically Affected Zone**: the region of weld that has been stirred and heated (TMAZ)
- **Tilt angle**: angle between the tool and the workpiece
- **Welding Procedure Specification**: a document that provides the qualified welding procedure