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பல்கலைக்கழகம்
ANNA
UNIVERSITY

FRICTION STIR WELDING

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Theory Subjects Handling

1. *Engineering Graphics*

2. *Advanced Welding and Casting*

3. *Non Traditional Machining Processes*

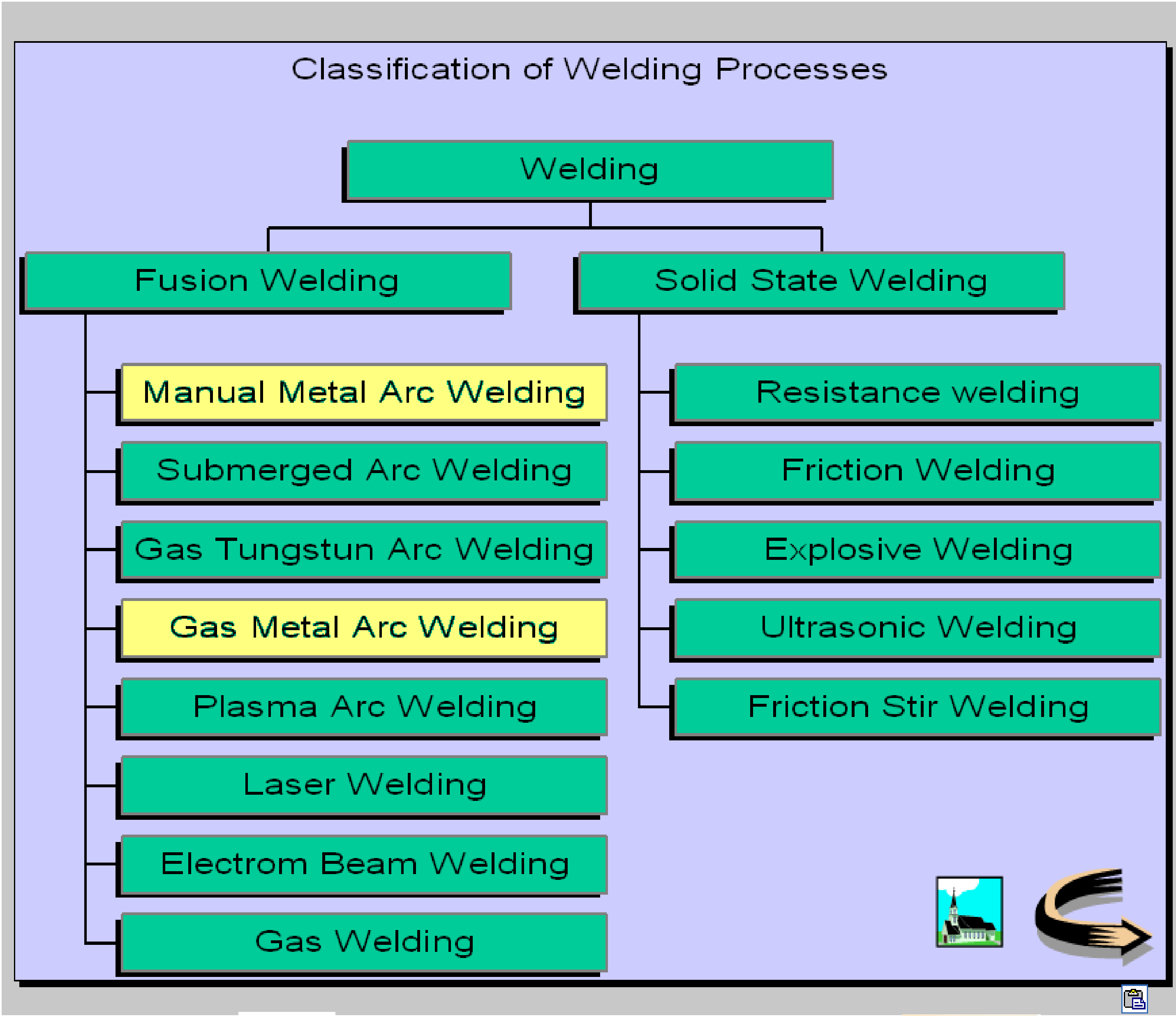
4. *Fluid Power Drives and Control etc.,*

Introduction of Engineering Drawing

intro.flv

Introduction of Advanced Casting

Foundry Sand Molding - YouTube.flv


Classification of Welding Processes
Welding
Fusion Welding
Solid State Welding
Manual Metal Arc Welding
Submerged Arc Welding
Gas Tungstun Arc Welding
Gas Metal Arc Welding
Plasma Arc Welding
Laser Welding
Electrom Beam Welding
Gas Welding
Resistance welding
Friction Welding
Explosive Welding
Ultrasonic Welding
Friction Stir Welding

Introduction of Advanced Welding

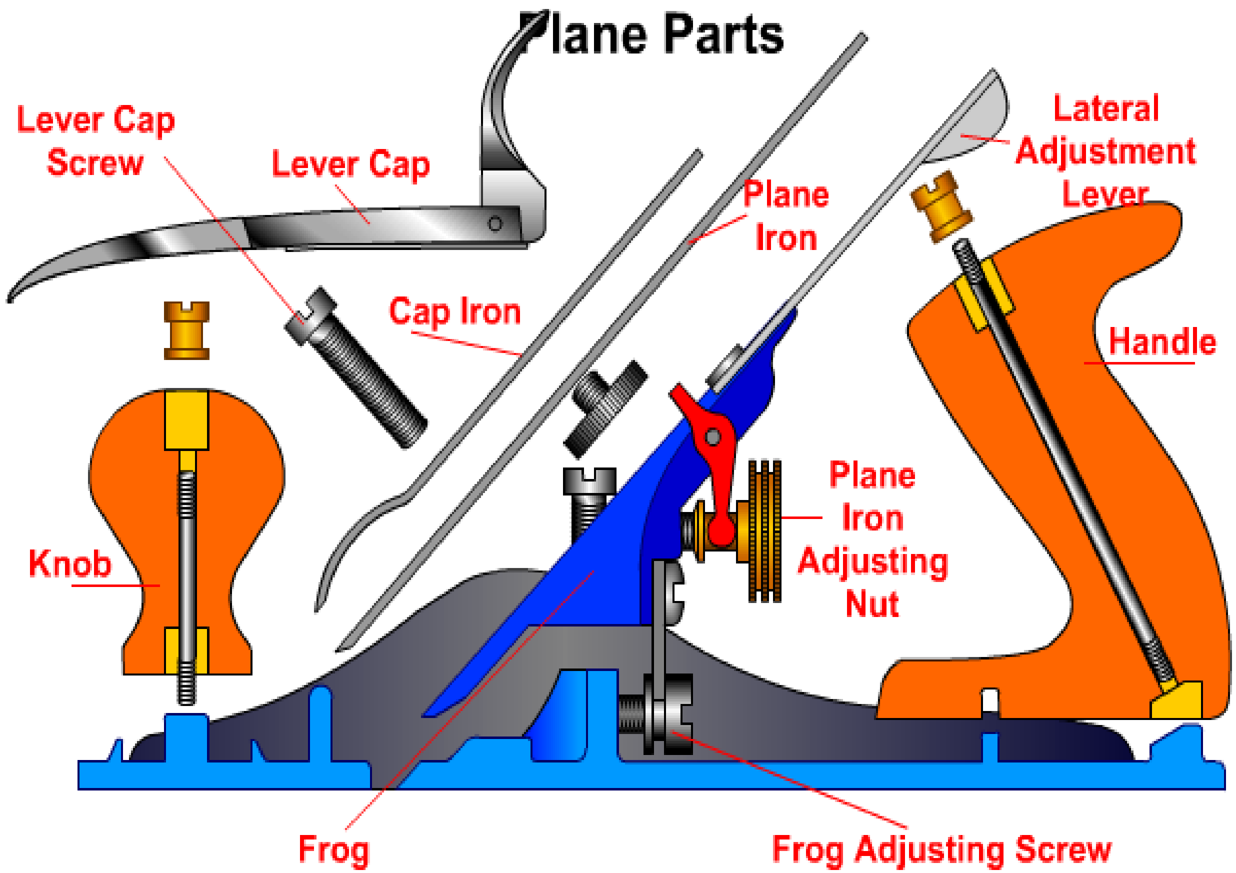
Thermite welding Railway Tech Switzerland - YouTube.FLV

Practical Laboratory Handling

1. *Engineering Practices Lab*
2. *Fluid Power Automation Lab*
3. *Material Testing Lab*
4. *Conventional Machining Lab etc.,*

Introduction of Engineering Practices Lab Video

Go to Engineering Practices Lab Videos



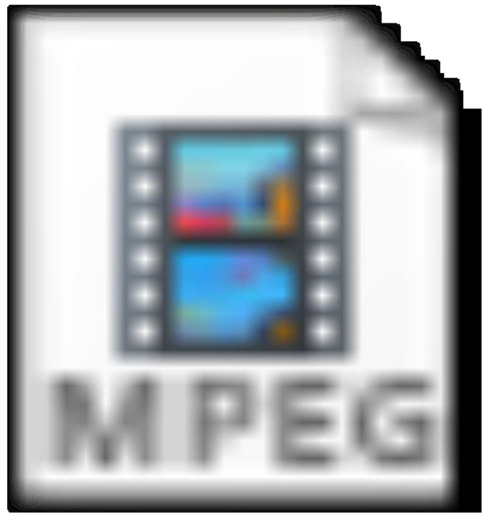
Introduction of FSW

FRICTION STIR WELDING (FSW) was invented at The Welding Institute (TWI) of the United Kingdom in 1991 as a Solid- State joining technique and was initially applied to aluminium alloys.

FRICTION STIR WELDING MACHINE

FSW Video-1

FSW Video -2



FSW2.MPA

FRICTION STIR WELDING MACHINE

MIT Milling Machine FSW Video

video-2012-11-26-09-35-51.mp4

MIT Milling Machine FSW - Spot Welding with Vertical Force

video-2012-11-26-09-37-49.mp4

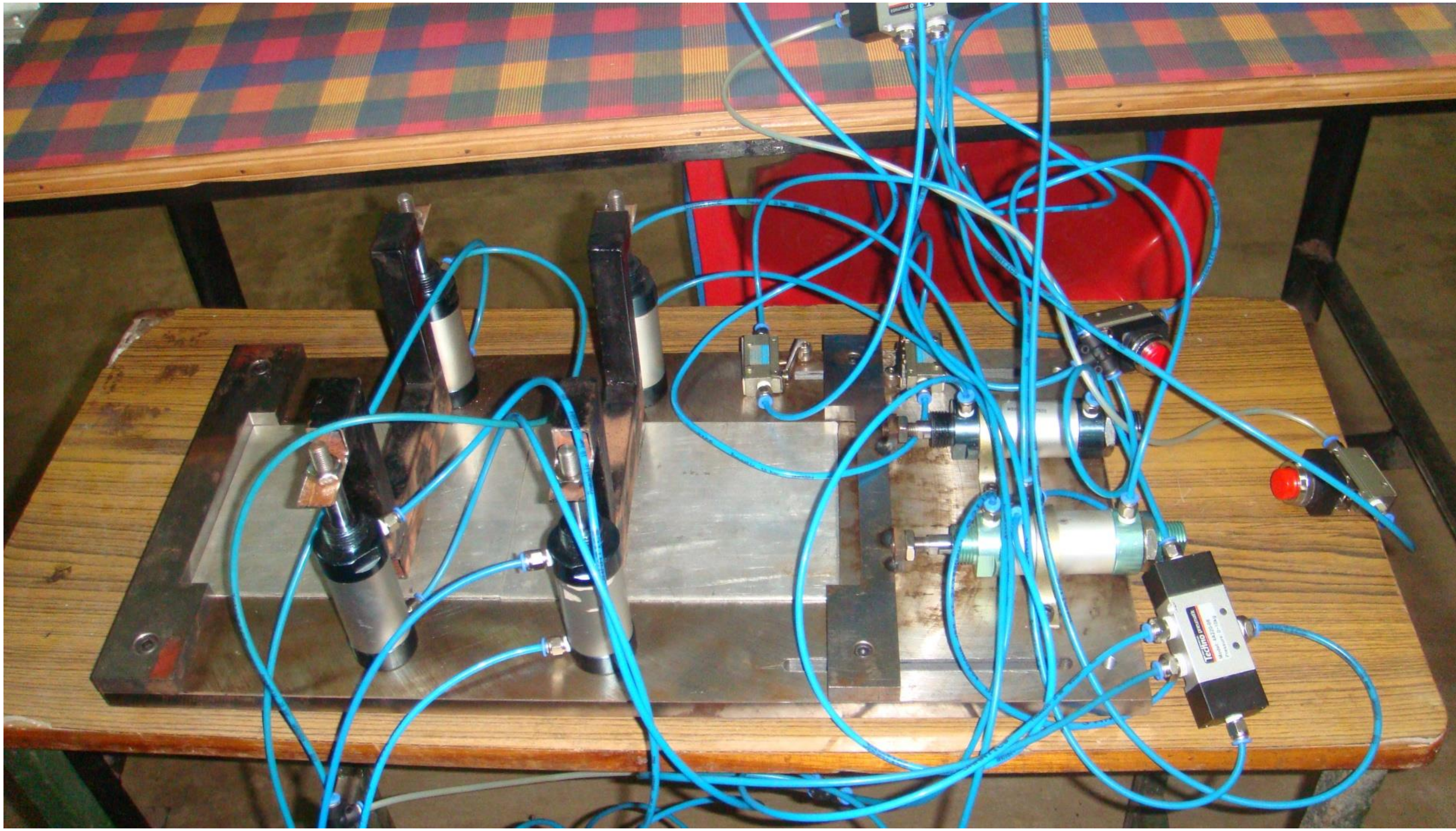
Department of Production Technology,
MIT, Anna University, Chennai-44

Vertical Milling Machine at MIT

MIT Milling Machine - FSW Spot Welding

video-2012-11-26-09-35-51.mp4

FSW Pneumatic Clamp



Introduction Cont..

- Friction Stir Welding is considered to be one of the most significant welding techniques to emerge in the last 20 years.
- Currently, this welding technique is commercially used only for joining Al-alloys in several industries, such as ship building, high speed train manufacturing and aviation industry.

Introduction Cont..

- Standard length Al extrusion panels used in high speed cruise ships are currently joined by this method.
- Furthermore, this method is successfully used in welding of fuel tanks used in aerospace applications.
- This welding technique is also used in carriage manufacturing of high speed trains in Japan, for the production of hollow Al extrusions.

Introduction Cont..

- Even though the FSW technique was initially developed for Al-alloys, it also has great potential for welding of Mg, Cu, Ti, Al-alloy matrix composites, lead , some steels, stainless steels, thermoplastics and different material combinations.

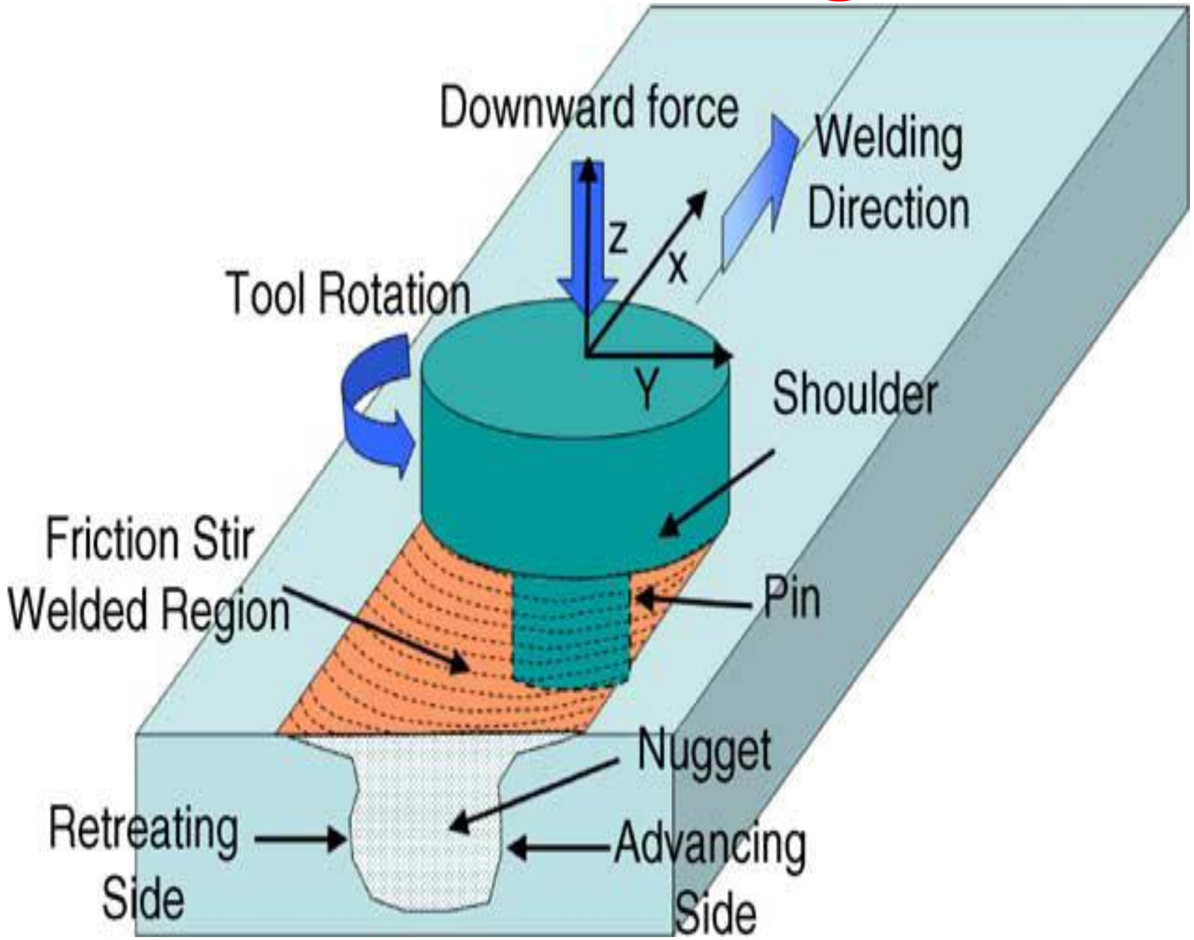
Introduction Cont…

- However, cost effective stirring tools are needed for welding some of these materials such as metal matrix composites (MMCs) and those with high melting temperatures. i.e., steels and Ti-alloys.

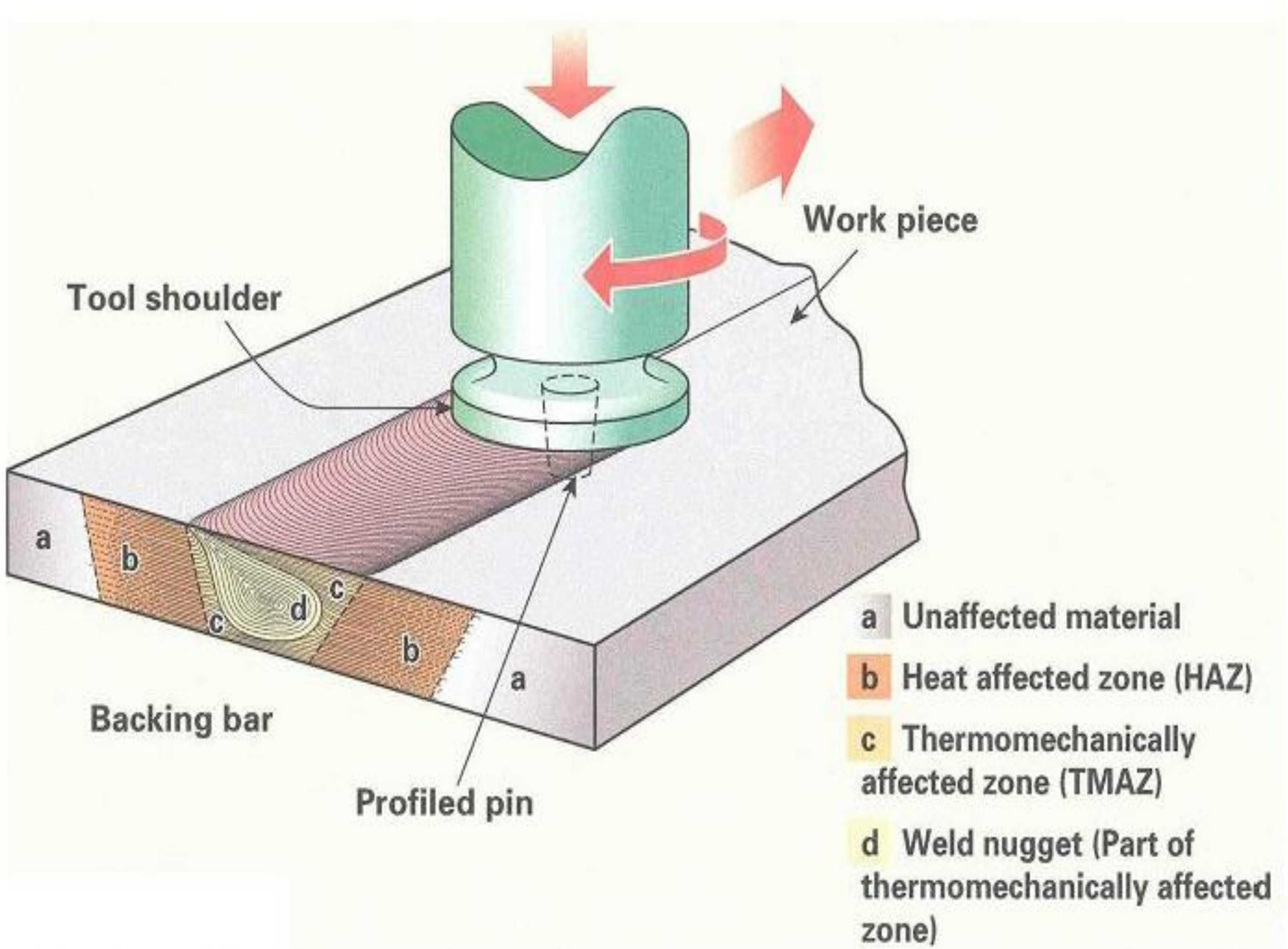
Introduction Cont…

- A non consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and subsequently traversed along the joint line.

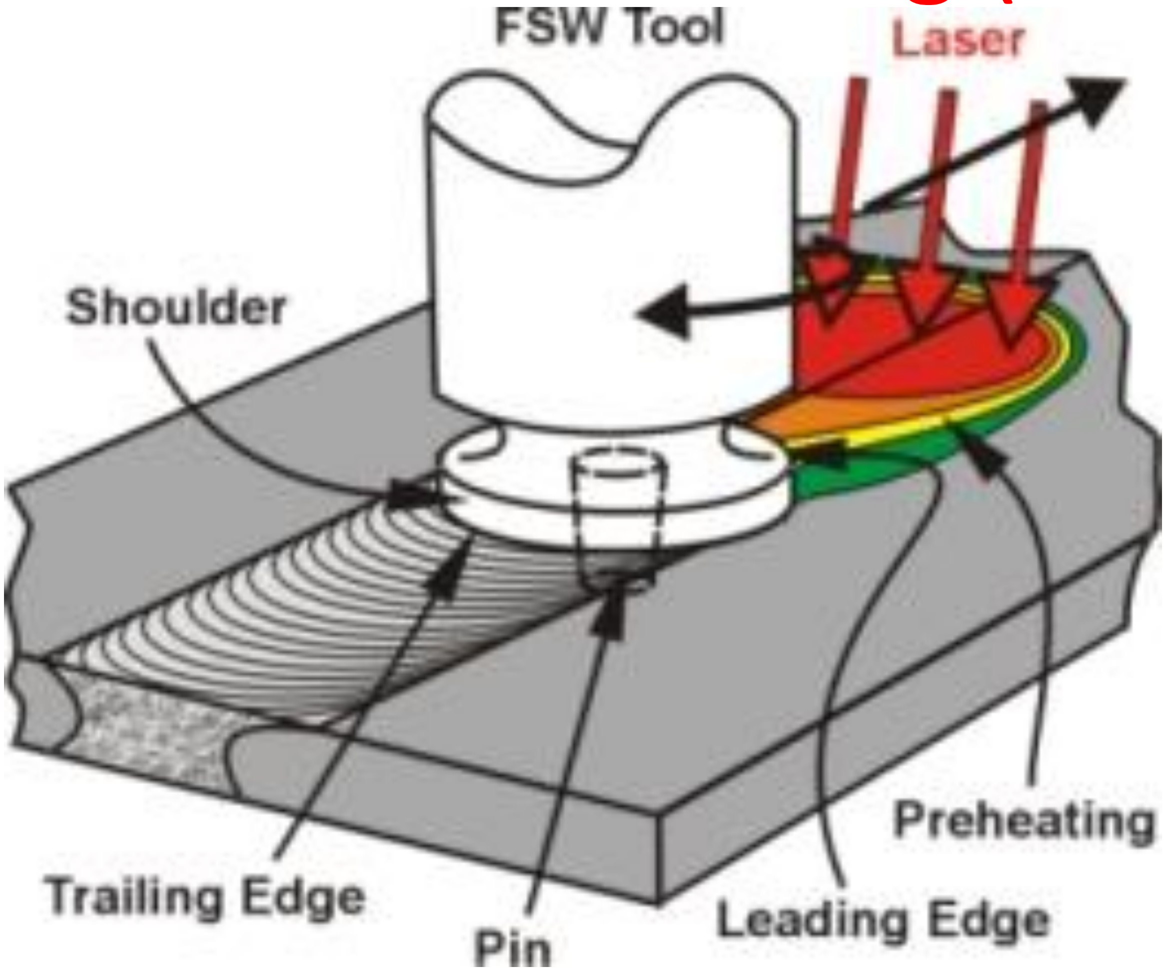
Schematic drawing of FSW



Principle of FSW



Friction Stir Welding (FSW)



FSW- Green Technology Cont…

- FSW is considered to be the most significant development in metal joining in a decade and is a “green” technology due to its energy efficiency, environmentally friendliness and versatility.

Key benefits of friction stir welding

- Metallurgical benefits
- Solid phase process
- Low distortion
- Good dimensional stability and repeatability
- No loss of alloying elements
- Excellent metallurgical properties in the joint area
- Fine recrystallized microstructure
- Absence of solidification cracking
- Replace multiple parts joined by fasteners
- Weld all aluminium alloys
- Post-FSW formability

Key benefits of FSW   Cont..

- Environmental benefits
- No shielding gas required
- Minimal surface cleaning required
- Eliminate grinding wastes
- Eliminate solvents required for degreasing
- Consumable materials saving such as rugs, wire or any other gases
- No harmful emissions

Key benefits of FSW Cont..

- Energy benefits
- Improved materials use (e.g., Joining different thickness) allows reduction in weight.
- Only 2.5% of energy needed for a laser weld
- Decreased fuel consumption in lightweight aircrafts, automotive and ship applications.

Functions of FSW tool

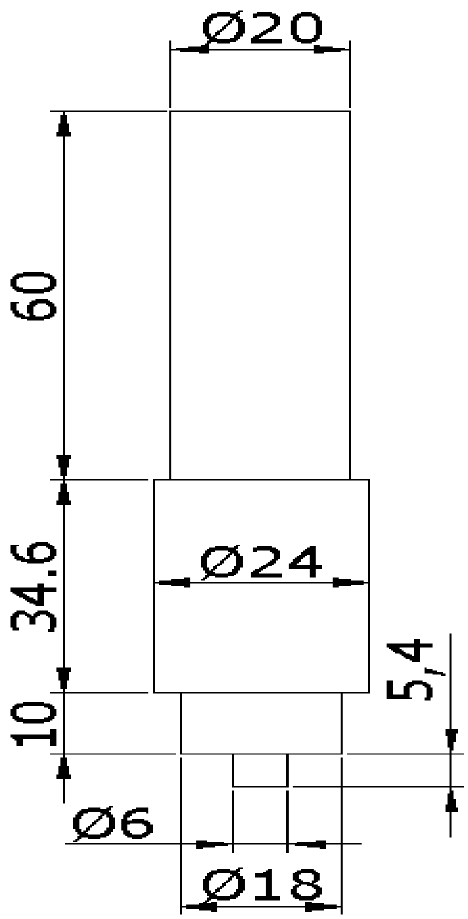
- The tool serves three primary functions, that is, heating of the workpiece, movement of material to produce the joint and containment of the hot metal beneath the tool shoulder.

Tool Material

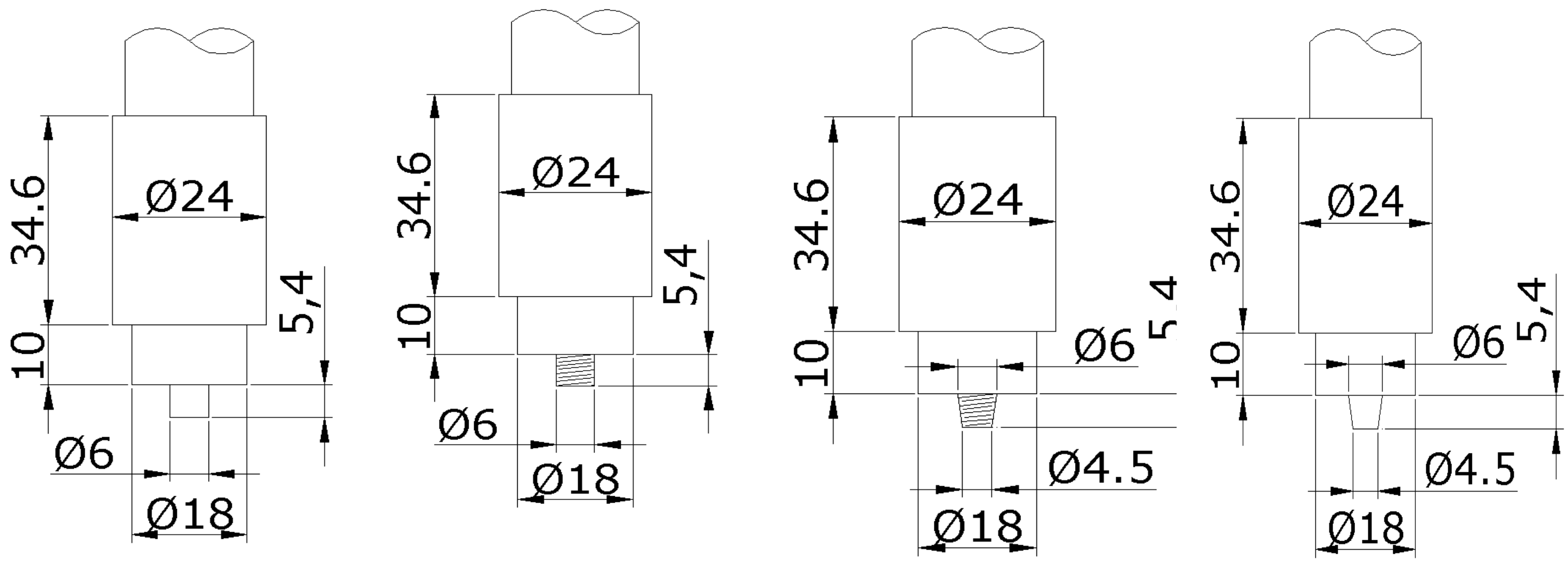
- 1. H13 (High Speed Tool Steel)
- 2. M2 (High Speed Tool Steel)
- 3. PCBN (Poly Crystalline Boron Nitride)
- 4. W-Re (Tungsten Rhenium alloy)

Different Profiles of tools used in FSW

Dimension of Tool and Pin



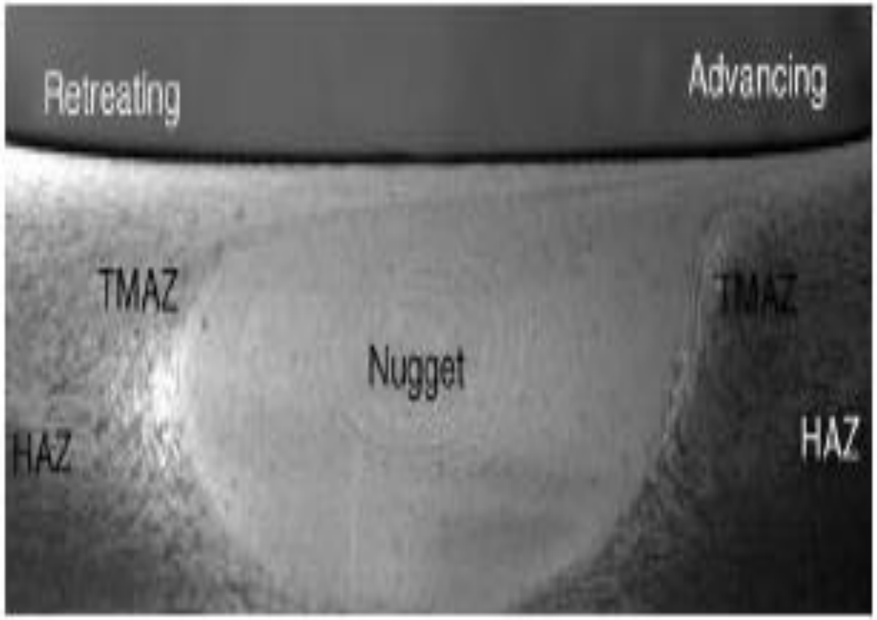
Different Tool Pin Profiles



Process Parameters in FSW

- Tool geometry
- Tool rotational rate (ω, rpm)
- (Clock wise or Counter clock wise)
- Tool travel speed (v, mm/min)
- Tool tilt angle (Degrees)
- Tool pin profiles
- Vertical force (kN)

Different weld zones in FSW



FSW Macrograph

MICROSTRUCTURAL ZONES IN FSW

S.No	Region	Material flow	Temperature
1	Weld Nugget(WN) or (SZ) Stirred Zone	High	High
2	TMAZ (Thermo mechanically affected zone)	Low	Medium
3	HAZ (Heat affected zone)	None	Medium

Applications

1. Automotive (Wheel rims)
2. Aerospace (Fuel tanks of space vehicles)
3. Shipbuilding (Hulls and superstructures)
4. Defence (Helicopter landing Platforms)
5. Recreation(Sailing boats)
6. Transportation (Aluminium bridges)
7. Containers (Truck bodies)

Current research

Aluminium and Magnesium alloys are successfully joined by FSW process.

Welding of Copper and its alloys, Steels, Stainless steels and Titanium alloys are under the research.

Need for the study

The effect of FSW parameters like tool geometry, tool rotational speed and speed of the welding on microstructure and mechanical behaviour have not been investigated fully for copper and its alloys.

Objective

In this juncture the objective of this research is investigating the effect of FSW process parameters on the Mechanical behavior and Microstructure of Copper and its alloys weld joints .

The Specific Objective of the Study are

1. Design and fabrication of friction stir pin of various profiles.
2. Investigating the effect of process parameters such as welding speed, tool rotational speed and tool angle of tilt.
3. To study the mechanical behaviors such as hardness, bend behaviour and tensile strength.
4. To examine the microstructure of the weld joints and correlating the same to the mechanical properties.

Chemical composition of Tool Material M2

Element	C	Si	Mn	Cr	Mo	V	W
Wt%	0.9	0.3	0.3	4.1	5.0	1.8	6.0

Hardening processes

↓

Austeniting (Temp:850^{0}C and Time: 1 Hr)

↓

Quenching in Oil (Temp:1200^{0}C)

↓

Tempering (Temp: 550^{0}C; Time:1 Hr)

Chemical Composition of Weld Material

Element	Zn	Pb	Sn	Fe	Ni	Si	Al	Mg	P	Cu
Wt %	0.010	0.011	0.010	0.005	0.044	0.005	0.002	-	0.020	99.863
Wt %	41.143	2.743	0.294	0.362	0.228	0.017	0.013	0.046	-	55.143

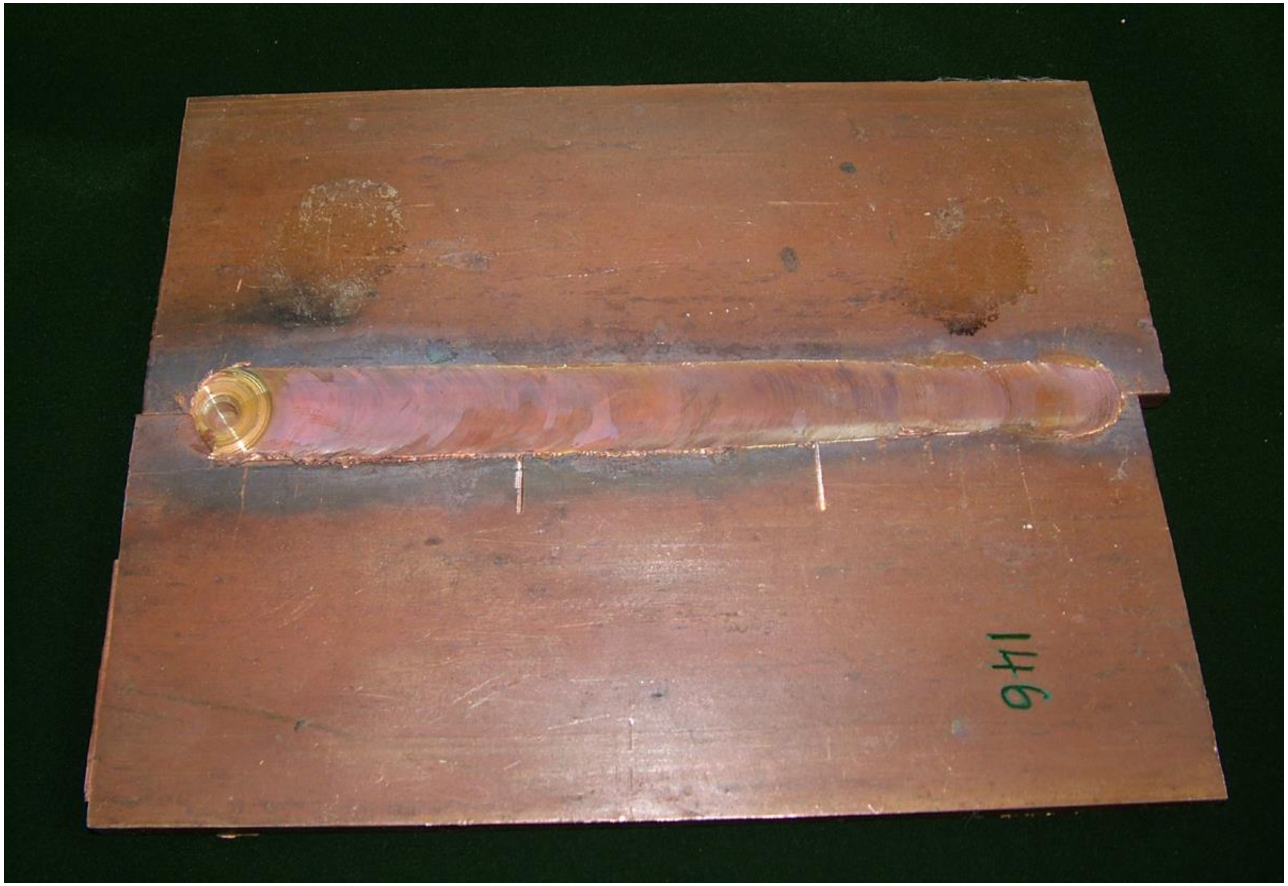
Experimental Procedure

- In this study, commercial pure copper and brass plates of dimensions 200 mm length 100 mm width and 6 mm thickness were welded by FSW.
- Tool rotation speeds ranging from 1300 to 1600rpm and traverse speeds of 30mm/min to 75mm/min were employed.
- The welding tool was tilted up by an angle of 2- 3 degree.
- Several sets of FSW experiments were conducted with various combinations.
- Four sets of experiments were chosen from the best resulted experiments with various combinations for further study.

Experimental Procedure Cont..

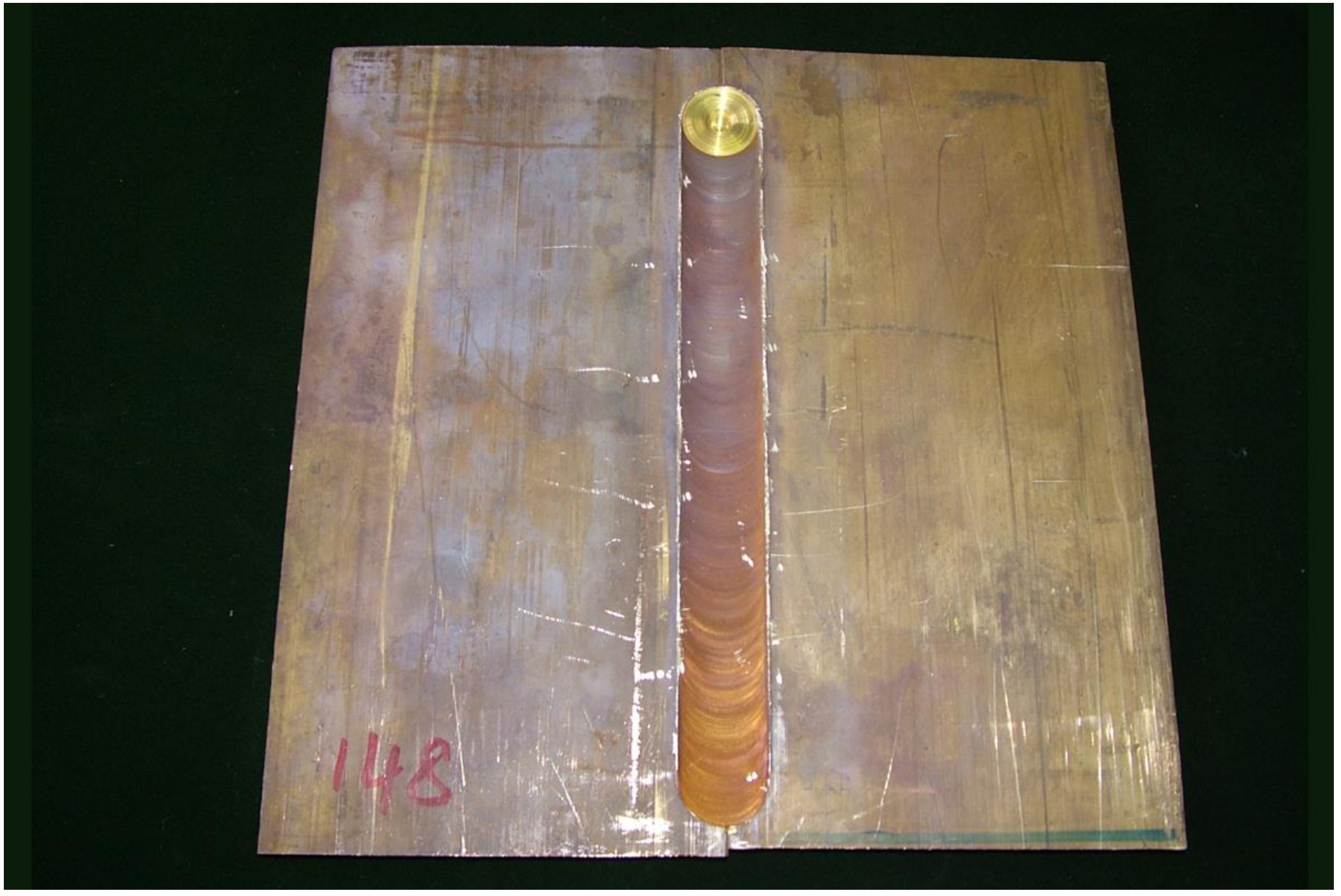
- Testing and Analysis
- 1. Visual Inspection
- 2. Microstructure
- 3. Hardness
- 4. Tensile properties (Strength, elongation and Joint efficiency)
- 5. Bend test

Results -Copper to Copper Weld



Defect free welds are obtained using 1300rpm and 45 mm/min

Brass to Brass Weld



Defect free welds are obtained using 1400rpm and 75 mm/min

Copper to Brass Weld

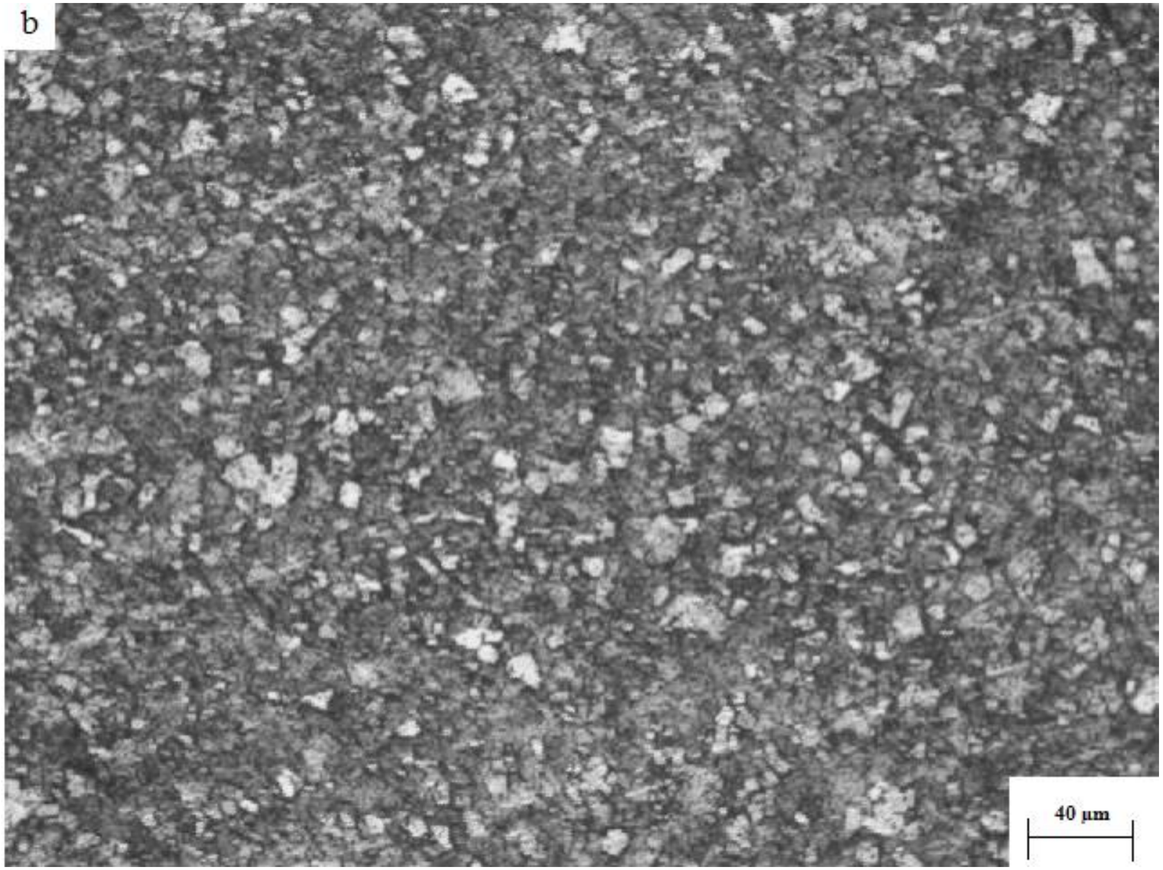
Defect free welds are obtained using 1600rpm and 50 mm/min

Microstructure of Base Metal Copper

Microstructure of Base Metal Copper

The microstructure of the base material ie., cold rolled copper plate revealed the presence of elongated grains of length ranging between 20 - 30µm and width of about 10µm.

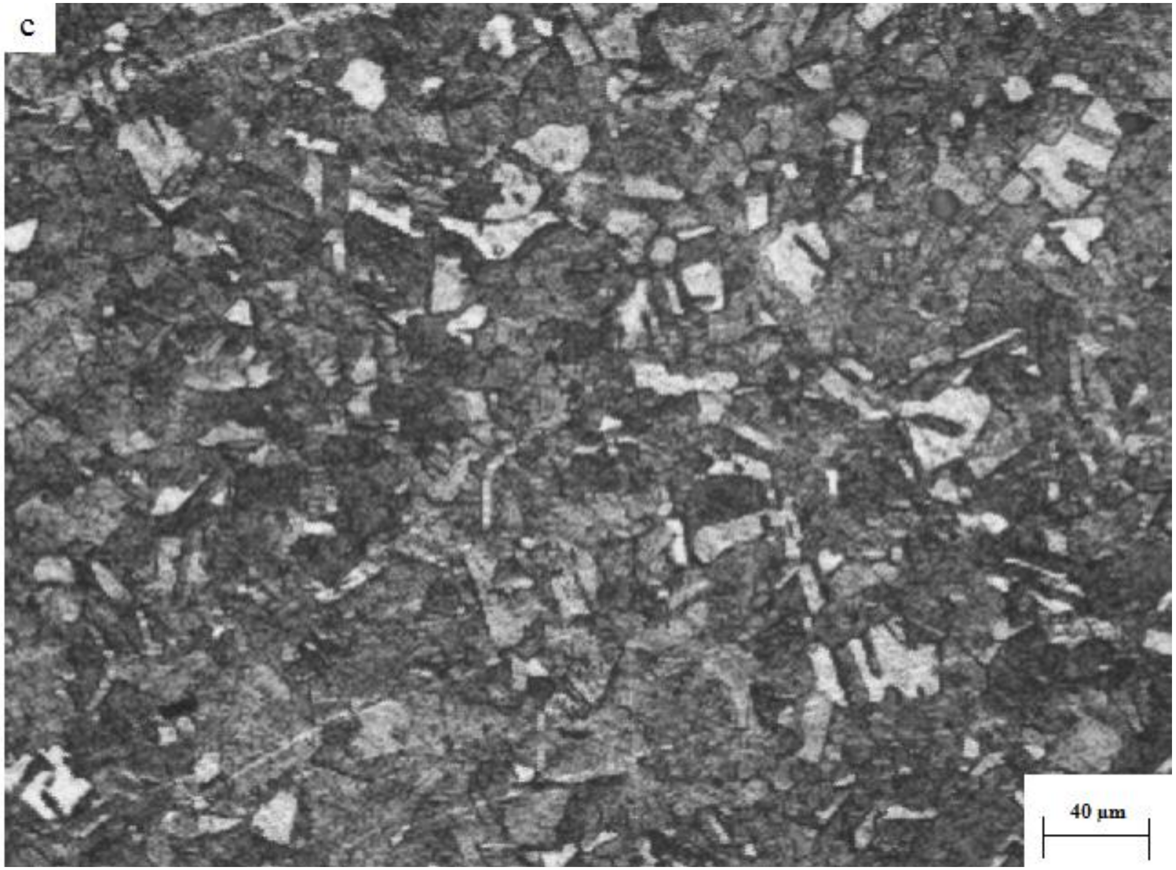
Microstructure of Weld Nugget Zone Copper



Microstructure of Weld Nugget Zone Copper

Weld Nugget reveals that porosity or other defects are not present in the nugget zone of all the joints produced. The nugget zone reveals the presence of refined equiaxed grains of size 1-2 microns. This observation indicates the occurrence of a complete recrystallisation in the nugget zone. Fine equiaxed grains were found to be distributed throughout the nugget zone

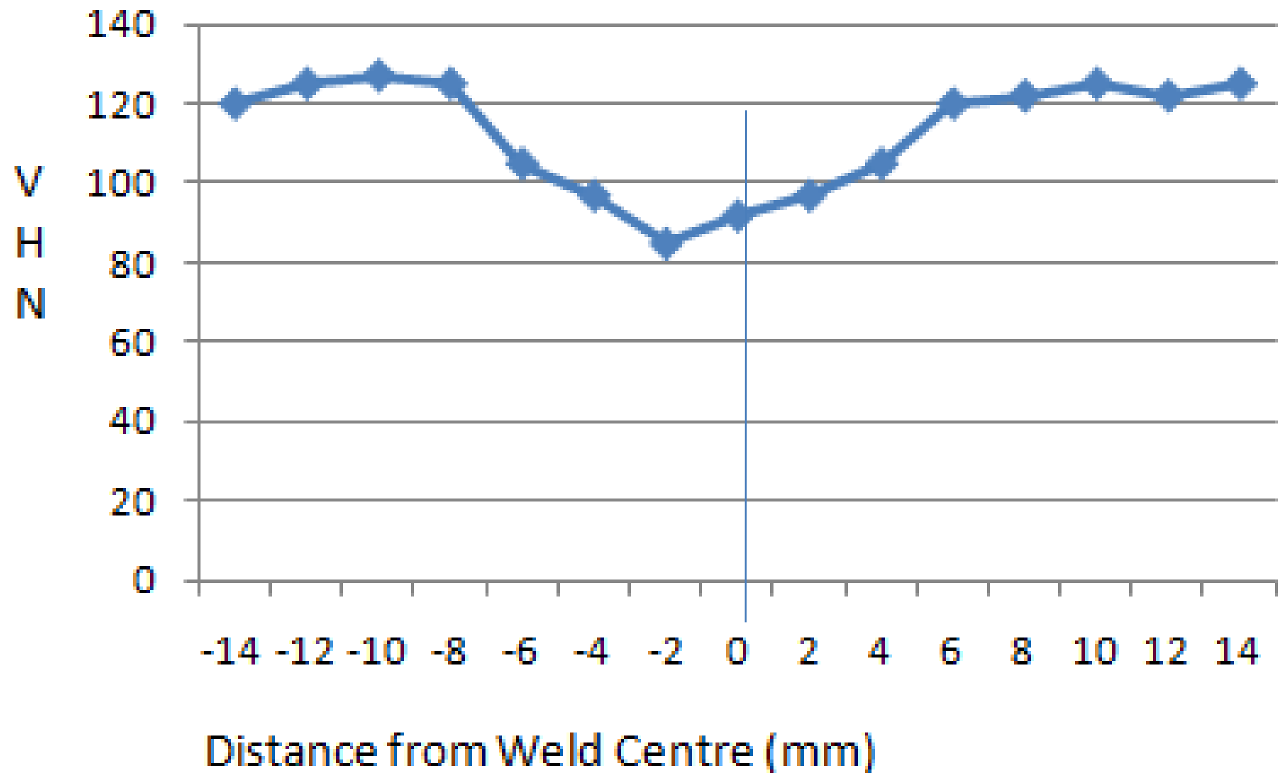
Microstructure of Heat Affected Zone Copper



Microstructure of HAZ Copper

The microstructure of the HAZ, wherein a partial recrystallisation resulting in equiaxed grains of size ranging between 5-10μm could be seen. A small increment in grain size in HAZ was also noticed.

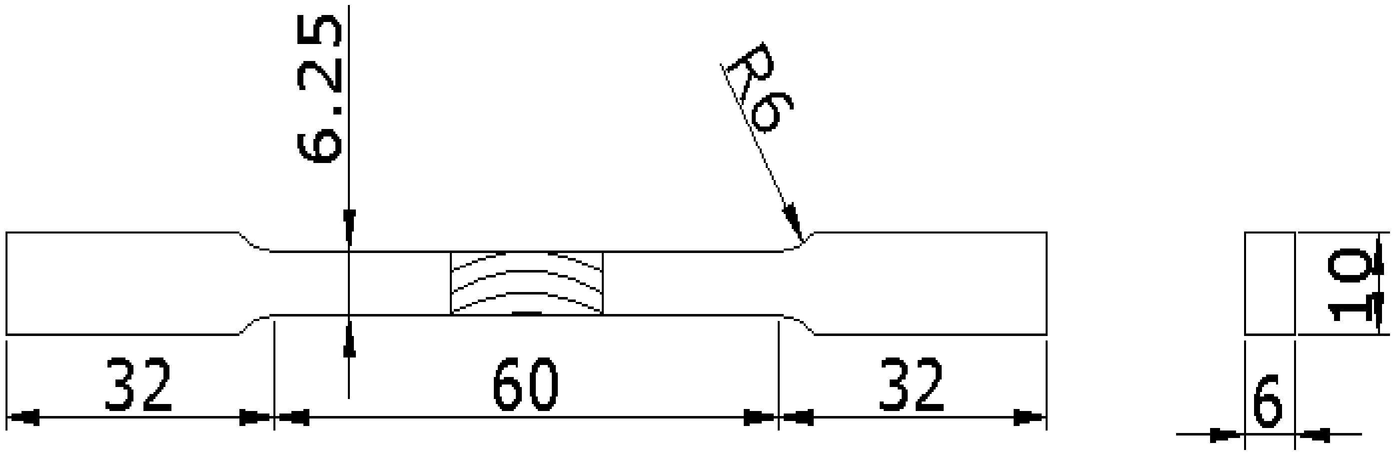
Hardness Traverse Curve Copper



Hardness Traverse Curve

The hardness of base metal copper ranged from 120 to 125 VHN, However, the hardness near weld nugget shows values from 85 to 92VHN. The weld centre has slightly lower hardness than that of the base metal in spite of smaller grain size. This could be attributed to the occurrence of annealing effect.

Tensile specimen preparation ASTM E8 Sub-size Dimensions



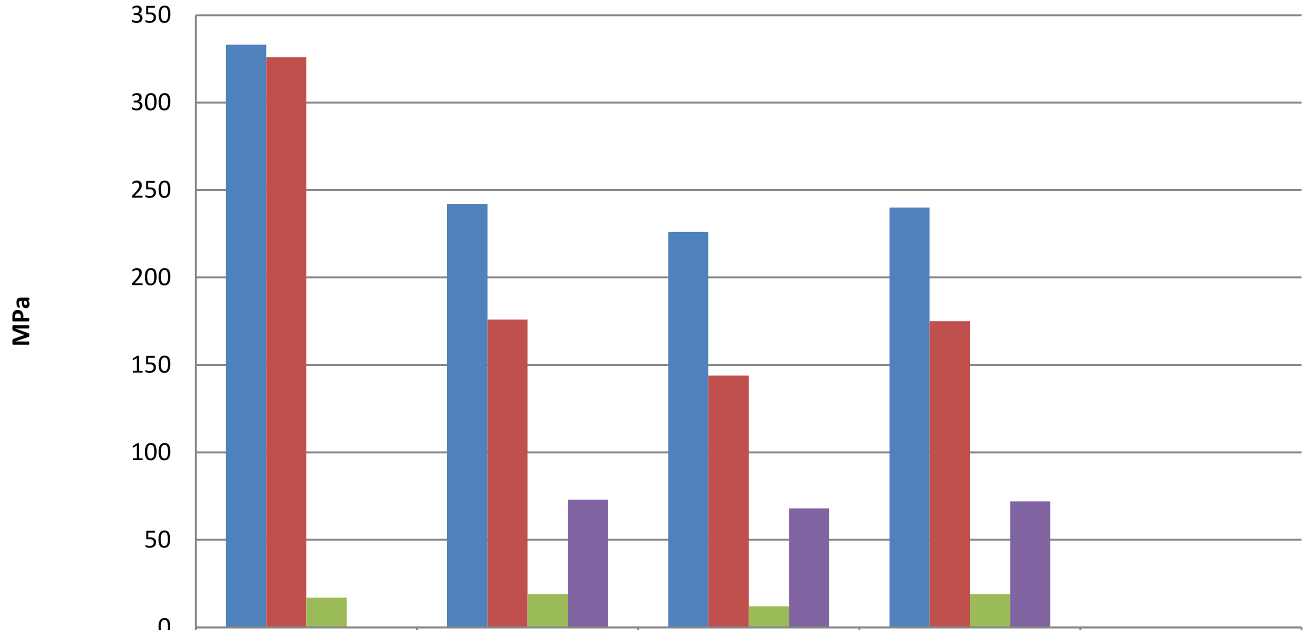
ASTM E8 Sub-size Tensile specimens

Tool rotational speed1300 rpm, Welding speed 45mm/min

Comparison of the Tensile Test Results of the Base Plate of and the Joint Produced

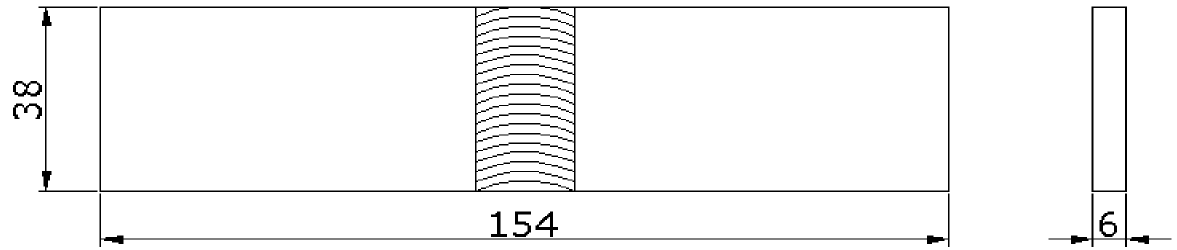
Rotational Speed RPM	Welding Speed mm/min	Tool Pin profile used	Tensile Strength MPa	0.2% proof stress MPa	Elongation %	Joint Efficiency %	Fracture location	Remarks
			333	326	17		Middle	Base Metal
1300	30	TTC	242	176	19	73	HAZ	Sound weld
1300	45	TTC	226	144	12	68	HAZ	Sound weld
1400	30	TTC	240	175	19	72	HAZ	Sound weld
1600	45	TTC	239	174	18	71	HAZ	Sound weld

Comparison of Engineering UTS , 0.2% Proof Stress, Elongation and Joint Efficiency for different BM & Welds



	1	2	3	4	5
Series1	333	242	226	240	UTS
Series2	326	176	144	175	0.2% Proof stress
Series3	17	19	12	19	% of Elongation
Series4		73	68	72	Joint η

Bend test

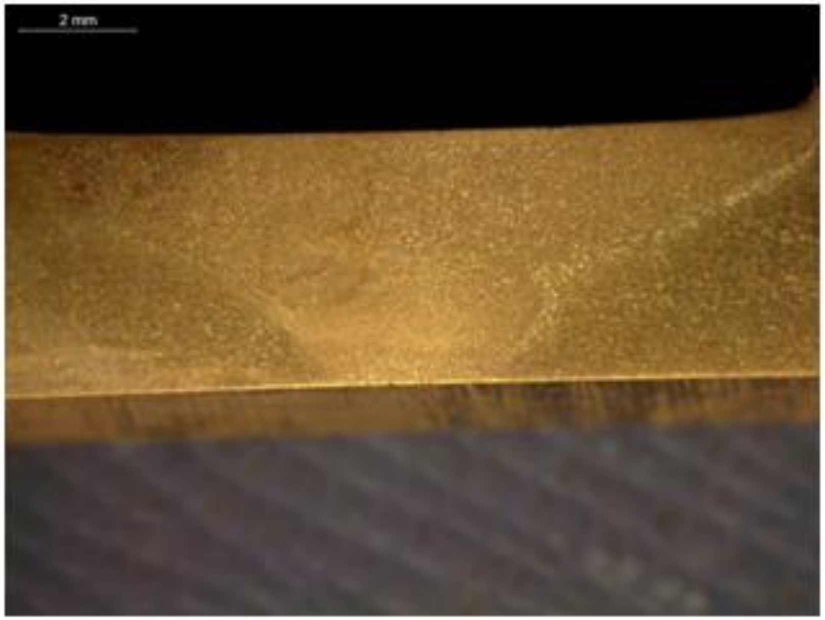


ASTM B4 Bend test specimen

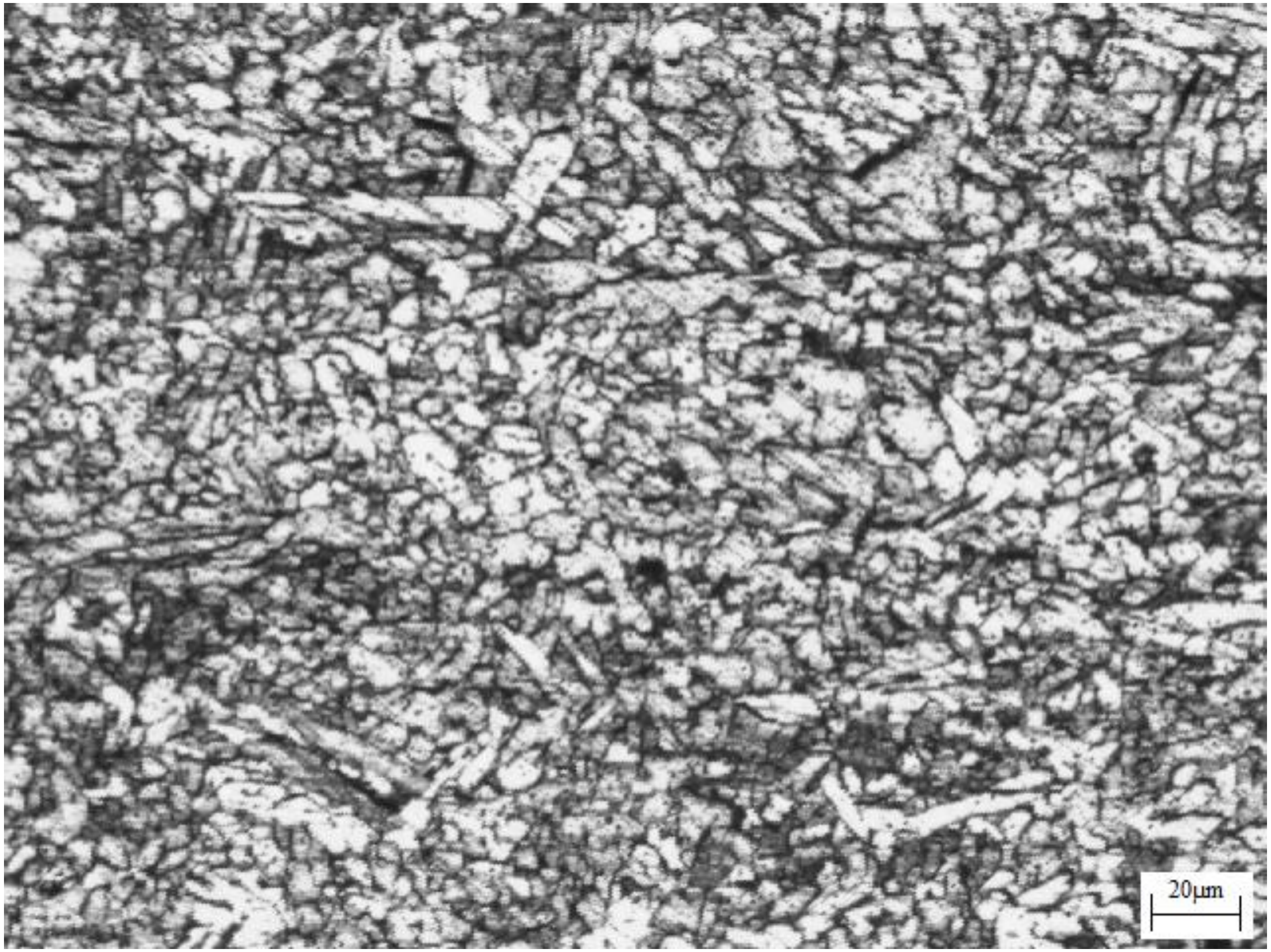
- The samples showed that, face bend of the welded plate withstood a maximum load of 4.5kN. The cracks were observed on retreating side of HAZ.

FRICTION STIR WELDED BRASS

Macrostructure of 7x



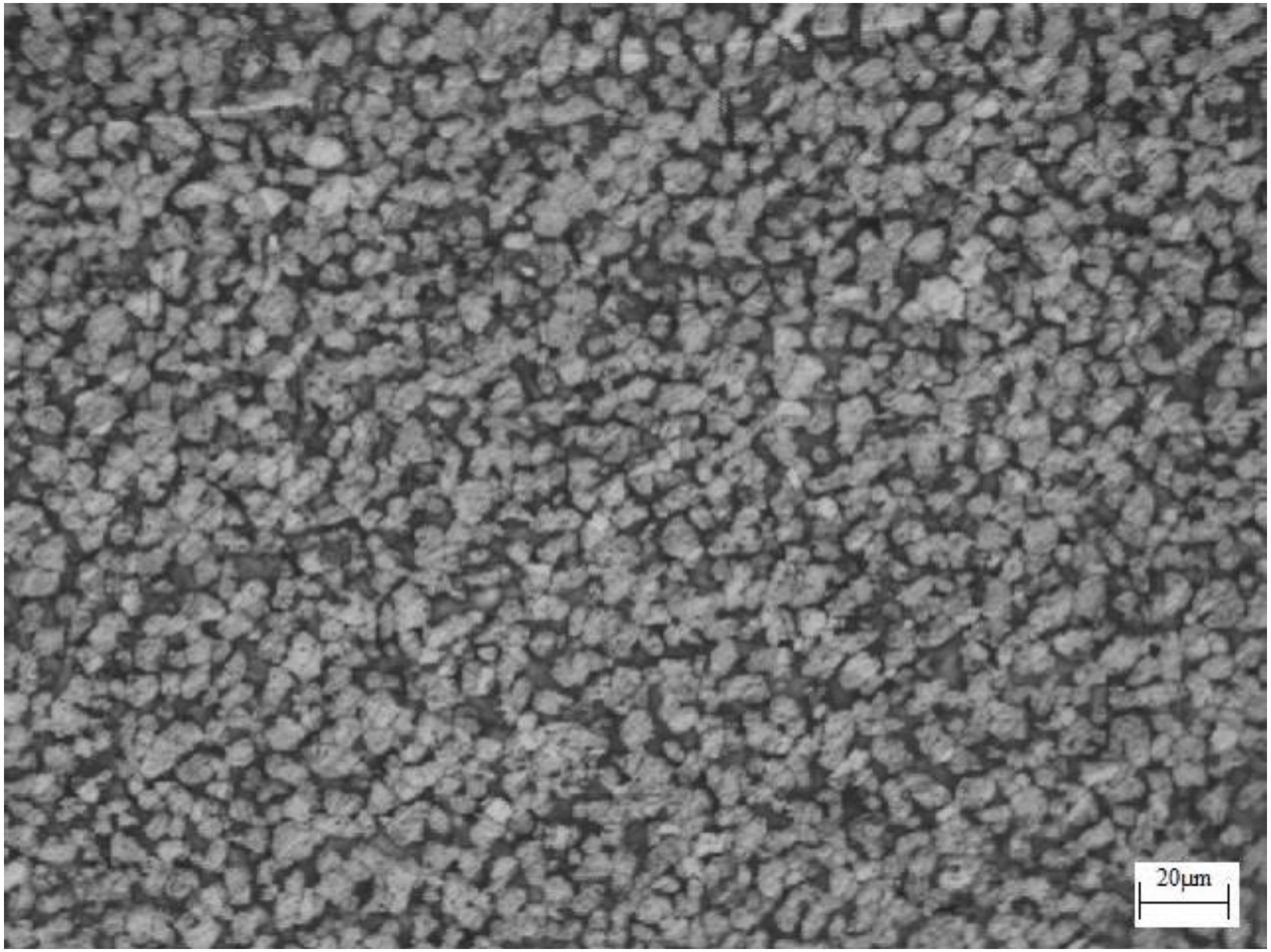
Microstructure Base Metal Brass



Base Metal Microstructure Brass

- The microstructure of the base plate (60/40 brass) is duplex consisting of $\alpha + \beta$ phases. The grain shape is also found to be a duplex mixture of elongated and equiaxed. The microstructure of the base material ie cold rolled brass plate revealed the presence of elongated grains of length ranging between 20 - 30µm and width of about 10µm Fig.

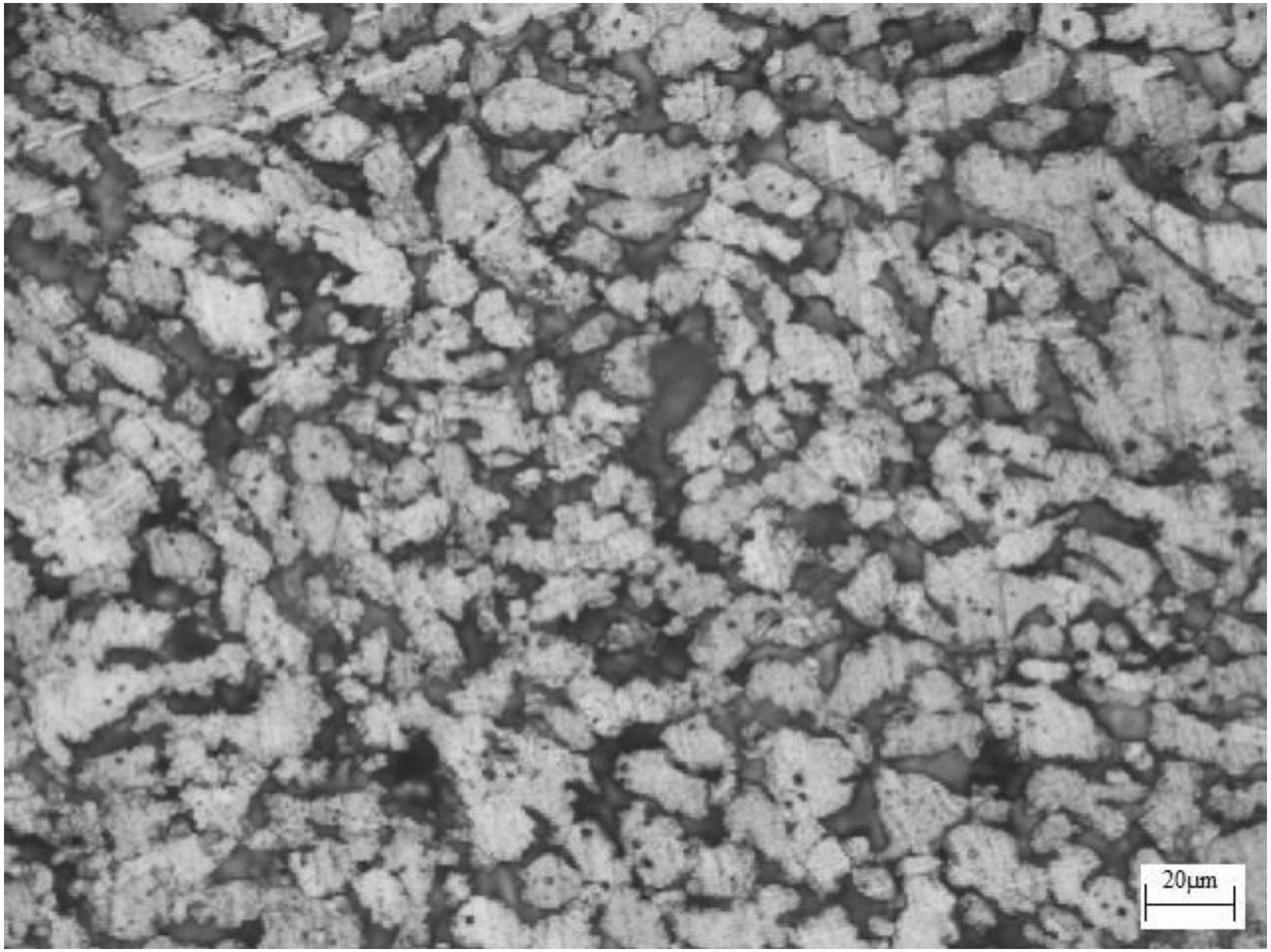
Microstructure of NZ Brass



Microstructure of Nugget Zone Brass

- The microstructure of the nugget zone (NZ) shown in Fig. The microstructure of the nugget zone of the brass plates welded with 1400rpm of tool rotational speed and traverse speed of 45mm/min. This revealed that no porosity or other defects are not present in the nugget zone of all the joints produced. The nugget zone reveals the presence of refined equiaxed grains of size 1-2 microns. This observation indicates the occurrence of a complete recrystallisation in the nugget zone.

Microstructure of HAZ Brass



Microstructure of HAZ Brass

- The microstructure of the HAZ, wherein a partial recrystallisation resulting in equiaxed grains of size ranging between 5-10µm could be seen. The friction stir welding resulted in a grain refinement within the nugget zone. The finest grain size was observed in the nugget zone of the joint produced with a traverse speed of 45mm/min and a rotational speed of 1400 rpm. Fine equiaxed grains were found to be distributed throughout the nugget zone and a small increment in grain size in HAZ was also noticed.

Comparison of the Tensile Test Results of the Base Plate and the Joint Produced

Rotational Speed RPM	Welding Speed mm/min	Tensile Strength MPa	0.2% proof stress MPa	Elongation %	Joint Efficiency %	Fracture location
		495	198	24		Middle
1400	45	242	200	06	48	HAZ
1400	75	241	200	06	48	HAZ
1600	45	240	200	05	48	HAZ
1600	60	243	202	05	49	HAZ
1400	75	194	168	05	39	HAZ
1400	45	287	250	13	58	HAZ
1600	45	271	250	13	55	HAZ

Tensile Behaviours of Brass

- Tensile test results of the base metal and FSW specimens along with the joint efficiency calculated with reference to the UTS of base material are given in Table.
- The best combination of mechanical properties was obtained for a tool rotational speed of 1400 rpm with a traverse speed of 45 mm/min in brass to brass weld. The tensile strength and percentage of elongation of the brass base material were 495 MPa and 13% respectively.

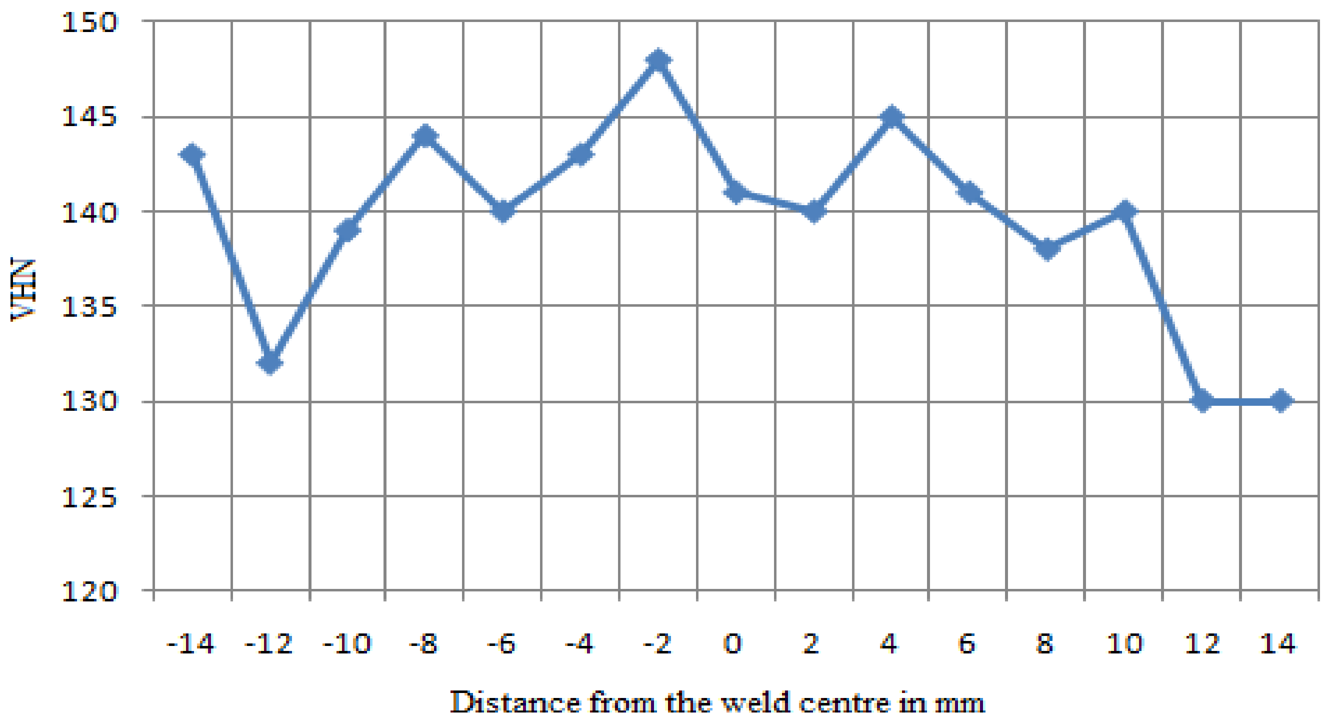
Tensile behaviour cont..

- Whereas the tensile strength and elongation of the best FSW joint was observed to be 271 MPa and 13% respectively for which the weld efficiency was found to be 58%. On increasing the spindle rotational speed and the traverse speed to 1600rpm and 45 mm/min, the joint efficiency and elongation were found to be 48% and 05% respectively. In this case, the fracture location of the weld joint was in the HAZ of the advancing side. Whereas in all other cases the fracture occurred along the weld line.

Hardness of Brass to Brass

- The hardness of brass-brass friction stir weld of base metal 140 to145 VHN, weld zone 155 to 167VHN, because at the centre of the weld equaxed fine grains with fine α-β phase mixtures were observed.

Hardness of Brass to Brass



Summary of the work

1. Nugget zone showed fine equiaxed grains of 1-2 micron size in comparison with the elongated grains of 20-30μm in the base metal of copper.
2. Hardness of the nugget zone was lower than that of base metal, because of annealing effect during welding.
3. Tensile strength and maximum joint efficiency obtained was 242 MPa and 73% respectively.
4. The percentage elongation was not affected in the welded plates.

Summary Cont..

5. The tensile fracture occurred in the HAZ at the advancing side of the weld due to the presence of few coarse grains

6. Defect free welds could be obtained using the following weld parameters. Viz., Tool rotational Speed ranging from 1300-1600, Welding speed ranging from 30-45 mm/min and tool tilt angle 3 degree.

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PUBLICATIONS

International Journal

1. International Journal of APPLIED ENVIRONMETAL SCIENCES (IJAES) Vol.9, No:2, July- Dec 2014. pp 165-172

   “**Microstructure and Mechanical Behaviour of Friction Stir Welded Brass**”

   N. Srirangarajalu, G. Madhusudhan Reddy, S.R. Koteswara Rao, A. Rajadurai

International Conferences

1. Joint International Conference on Advanced Materials -2011, ICAME 2011, 19th- 20th August 2011,BTL Institute of Technology, Bangalore.PJIC_122.

- “**Friction Stir Welding of Copper and its alloys”**

N. Srirangarajalu, G. Madhusudhan Reddy, S.R. Koteswara Rao, A. Rajadurai

2. International Conference in Magna On Emerging Engineering Trends (ICMEET -2K11), 11&12thh April 2011. Magna Engineering College, Chennai “Fabrication and Characterization of Ionoxide Nano Particles Reinfored Epoxy Resin Hybrid Nano Composite,

Arun Prakash V.R , **Srirangarajalu N**, A. Rajadurai

3. 2nd International Conference on Advances in Engineering and Technology (ICAET2012), March 28 & 29, 2012.

- “**Friction Stir Welding of Copper and its Alloys using Different Tool Pin Profiles”.**
- **N. Srirangarajalu**, G. Madhusudhan Reddy, S.R. Koteswara Rao,
- A. Rajadurai

International Conferences Cont..

- CiiT International Journal of Programmable Device Circuits and Systems Print: ISSN 0974 – 973X & Online: ISSN 0974 – 9624
- Issue: July 2012 :DOI: PDCS072012010
- **“Friction Stir Welding of Copper and its Alloys Using Different Tool Pin Profiles”**
- **N. Srirangarajalu**, G. Madhusudhan Reddy, S.R. Koteswara Rao, A. Rajadurai
- 4. 1st International Conference on Intelligent Robotics, Automation and Manufacturing, IRAM 2012;Kuala Lumpur;**Malaysia**,28 Nov. TO 30 November 2012;
- **“ Microstructure and Mechanical Behaviour of Friction Stir Welded Copper”**
- **N. Srirangarajalu**, G. Madhusudhan Reddy, S.R. Koteswara Rao, A. Rajadurai
- Code94343: Volume 330 CCIS, 2012, Pages 458-465,
- **Springer and Scopus Indexed.**

Publication Cont..

5. International Conference on Engineering Materials and Processes, ICEMAP 2013; Tagore Engineering College, Chennai on 23rd and 24th May 2013.

- **" Microstructure and Mechanical Behaviour of Friction Stir Welded Brass"**
- **N. Srirangarajalu**, G. Madhusudhan Reddy, S.R. Koteswara Rao, A. Rajadurai

6. International Conference in Magna on Emerging Engineering Trends (ICMEET-2K14) Magna College of Engineering, Chennai on 9&10 April 2014. " **Microstructural Investigation on Friction Stir Processed Al-Si Alloy"** Dasan Sisil Raj G, Srirangarajalu N

7. International Conference on Recent Innovations in Engineering (ICRIE'14), Sri Subramnya College of Engineering and Technology, Palani

"Influence of Process Parameters on Friction Stir Processing of Al-Si Alloy" Dasan Sisil Raj G, Srirangarajalu N.

8. International Conference (ICRTIEM 2014) Ranipettai Engineering College, Vellor,

"Studies and Optimization of Welding Parameters in CO_2 Welding of SS304 Material"

E. Thiyagarajan, **N. Srirangarajalu**

Publication Cont..

- 9. International Conference on Recent Trends in Engineering & Technology-2014 (ICRTET'14), at Oxford Engineering College, Polur, Thiruvannamalai.
- "Automatic Welding System for Varying Position and Orientation of Workpiece"
- C. Arun Prakash, N. Srirangarajalu

National Conferences

- 1. National Conference on Advances in Robotics, Precision Engineering & Manufacturing Techniques (AIRPAM -2008) Madras Institute of Technology, Anna University, Chennai on 14&15th March 2008 "**Friction Stir Welding of AA 5083**"

  N. Srirangarajalu, K. Subbaiah, B. Mohan, S.R. Koteswara Rao
- 2. National Conference on Recent Innovations in Production Engineering (RIPE - 2010)) Madras Institute of Technology, Anna University, Chennai on 16&17th April 2010 " **Effect of process parameters in Friction Stir Welding of dissimilar aluminium alloys**" T. Ganesh**, N. Srirangarajalu**, A. Rajadurai
- 3. National Conference on Recent Trends in Mechanical Engineering (RTME'11) GKM College of Engineering, Chennai **"Joining of Magnesium alloys by Friction Stir Welding**" V. Rahul **N. Srirangarajalu**
- 4. National Conference on Recent Trends in Manufacturing Sciences (RTMS'13) Dhanalakshmi Srinivasan College of Engineering and Technology, Chennai. "**Experimental Study on Friction Stir Spot Welded Aluminium"**

  Rajaprasanna **N. Srirangarajalu**

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- 5. 4th National Conference on Advances in Mechanical Engineering (BCAME-2014), Sri Balaji Chockalingam Engg. College, Arni**. "Effect of Pin Geometry on Bonding, Microstructure and Mechanical Properties In Friction Stir Welding of AA 2024-T3."** Anil Kumar S**, Srirangarajalu N.**
- 6. National Conference on Recent Trends in Electrical Technology (RTET 2K14) at Vels University, Chennai
- **"Vision Based Seam Tracking for Automatic Welding System**"
- C. Arun Prakash, N. Srirangarajalu

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