



Mohd Rashidi Asari



https://www.researchgate.net/profile/Rashidi_Asari



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World Automotive Body Trend

- Body Structure Material
- Joining Techniques of Car Body
- Joint Comparison



Welding Technology Implementation

- Adaptive Spot Welding System
- GMAW Welding Technology
- Non Destructive Weld Testing Method for Spot Welding



Welding Technology – Towards Cyber Physical System

- Introduction to Industry 4.0
- Automotive Welding Factory Assessment
- Welding Shop – Smart Factory
- Energy Consumption in Automotive Welding Shop
- Vertical – Horizontal Integration of Welding Technology
- Welding Process Simulation



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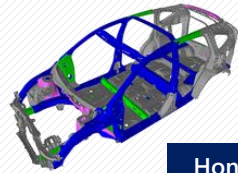
World Automotive Body Trend

- Body Structure Material
- Joining Technique of Car Body
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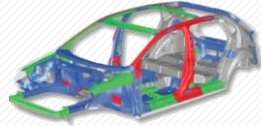


Global Trend



STEEL


Honda HRV



VW Polo



Ford Fusion

HYBRID



Mercedes E Class



Tesla Model 3



Audi A8



Aluminum


Jaguar X350



Range Rover

- Body weight reduction design while maintaining structure performance - stiffness, NVH, safety & durability
- 10% weight reduction may reduce up to 7% fuel consumption
- Aluminum may reduce body weight up to 40%
- Carbon fibre may reduce body weight up to 60%



Heavy



Light



High



Low



Less



More



Spot Welding

- Most common joining technique used in automotive industry
- Required double sided gun accessibility
- Applicable for hybrid joining (with structural adhesive)



MIG Welding

- Applicable for inaccessible position (single sided)
- Use shielding gas – CO₂ / Ag / Mix



Laser Welding

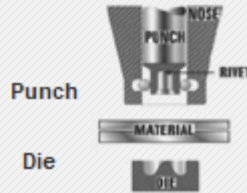
- Applicable for inaccessible position (single sided)
- Increase vehicle stiffness (no structural adhesive required)
- Suitable for lightweight body structure design (flange width reduction)

HYBRID



Clinching

- Applicable for Steel – Aluminum sheet combination
- Punch diameter – Up to Ø12 mm
- Total stack up – Up to 4 layers



Self Piercing Rivet

- Applicable for Steel – Aluminum casting combination
- Rivet diameter – Ø 3 or 5mm
- Total stack up – 2 layers only



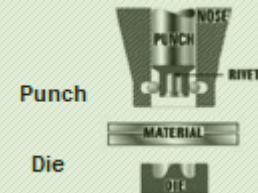
Structural Adhesive

- Applicable for hybrid joining → Clinching / SPR – Adhesive
- Increase vehicle stiffness & fatigue life of joint



Spot Welding

- Generally require 2.5X larger weld current than steel



Self Piercing Rivet

- Require pressing force up to 10x of welding force

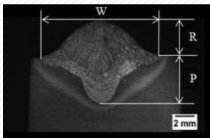


Structural Adhesive

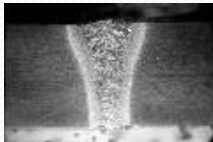
- Applicable for hybrid joining → Spot Weld / SPR – Adhesive
- Increase vehicle stiffness & fatigue life of joint



Spot Welding



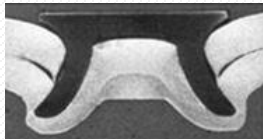
MIG Welding



Laser Welding



Clinching



Self Piercing Rivet

Strength (Shear, kN)	2	5	4	1	3
Energy Consumption (kWh)	4	3	2	1	5
Cost per Joint (Overall, RM)	3	5	2	1	4
Investment Expenditure, RM	2	3	5	1	4
Process Cycle Time, sec	2	5	4	1	3
Complexity of Operation	2	3	5	1	4
Hybrid Process with Adhesive	Yes	No	No	Yes	Yes

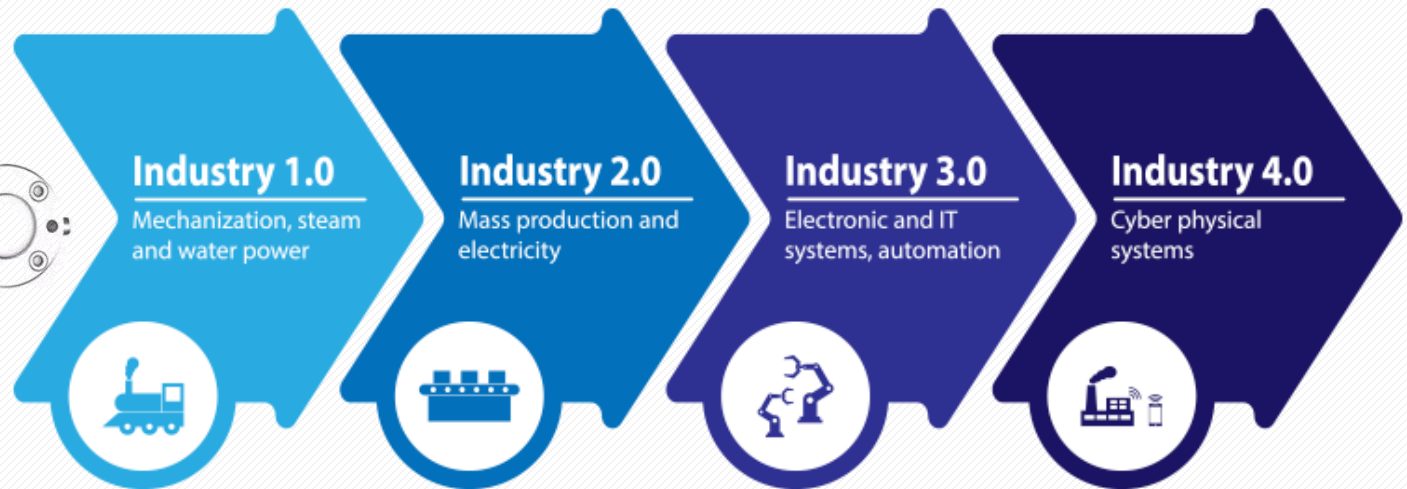
- Note:**
1. Energy consumption is calculated base on electrical energy consumed by the process
 2. Cost per joint is calculated including consumables, shielding gas & filler material
 3. Investment expenditure is initial purchasing cost of equipment, together with it auxiliary parts

Towards Cyber Physical System

- Industry 4.0 – An Introduction
- Automotive Welding Factory Assessment in Malaysia
- Energy Consumption in Automotive Welding Shop
- Welding Vertical – Horizontal Integration Technology
 - House Model Presentation of Welding System
 - Complete Architecture of Welding System
 - Energy Efficiency Matrix of Spot Welding
 - Vertical – Horizontal Integration of Spot Welding
- Welding Process Simulation
 - Welding Process Simulation in Automotive
 - Process Simulation modelling for Spot Welding

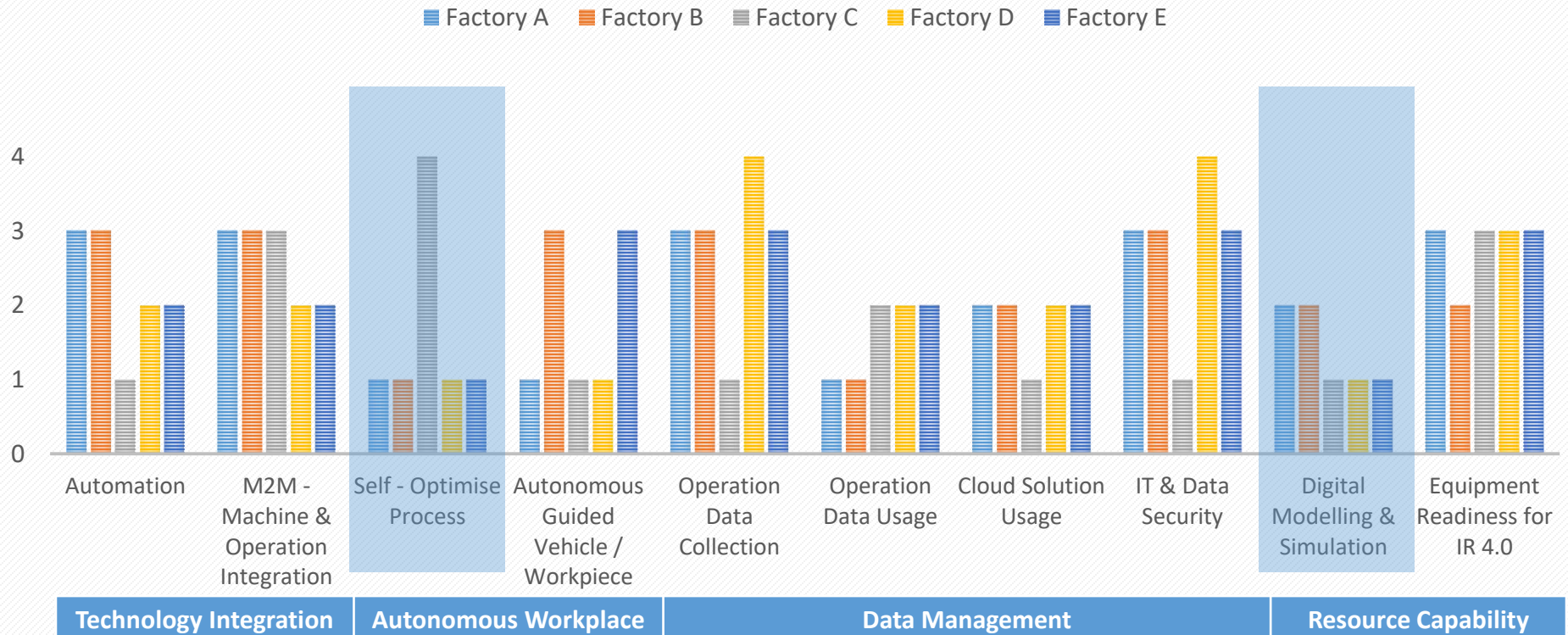


General Overview



Industry 4.0 refers to the fourth industrial revolution, which affects every manufacturing domain and comprises advanced manufacturing technologies that capture, optimize, and deploy data. In other words, Industry 4.0 makes factories “smart” by implementing such technologies as the industrial Internet of Things, artificial intelligence, and cyber-physical systems interact seamlessly, communicating and adjusting continuously. The following graphics represent 9 key technologies for IR 4.0



**Note:**

1. Welding factory assessment is done by using self-assessment tool established by University of Warwick for **manufacturing sector** in 2019
2. Welding technology in automotive industry moves inline with IR 4.0 especially in **'Self – Optimise Process'** and **'Digital Modelling & Simulation'** categories
3. Factory A & D use solar panels to generate electricity to reduce utility cost. Regardless of any advancement of the system, energy consumption must be efficient enough since it contribute the highest cost in factory operation

System Proposal

Production System

Body Welding Line



Body Fitting Line



Process Data Capture & Monitoring



Robot Controller

- Connected service (online troubleshooting)
- Online conditional base monitoring
- Predictive maintenance



Welding Controller

- Adaptive control system
- Process parameters capture / monitoring



PLC Controller

- Automated line monitoring
- Online trouble shooting

Smart Glasses

- Embedded with Augmented Reality (AR)
- Online troubleshooting support

Product Data Capture & Monitoring



CMM Controller

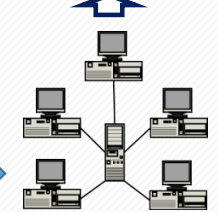
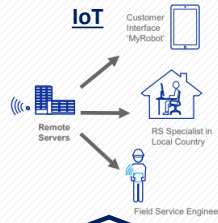
- Selected body accuracy data capture & monitoring – Datum & fitting related point

Production Report & C/Sheet

BIW Quality Report



Online Inspection / start up list



Central Computer – Data capture & monitoring

- Paperless concept
- Process parameters vs VIN
- Equipment error log & downtime trigger
- Online conditional base monitoring (CBM)
- Maintenance alarm trigger (predictive maintenance)
- Product quality capture & monitoring
- Online documents & checklist

Ethernet / LAN / Wireless

Torque Controller

- Error Log / monitoring
- Process parameters capture / monitoring



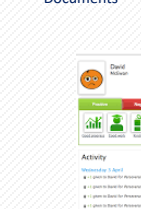
Electrical Impulse



- Data of height & gap capture / monitoring

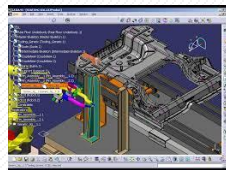


Collaborative robot



Manpower Attendance & Performance

Supporting Simulation Software



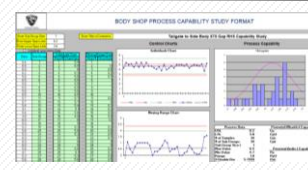
CATIA / AutoCAD



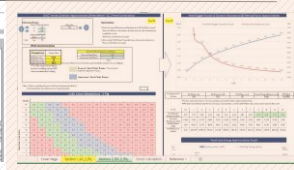
ABB RobotStudio



MTM (Process Time Study)



Process Capability Study



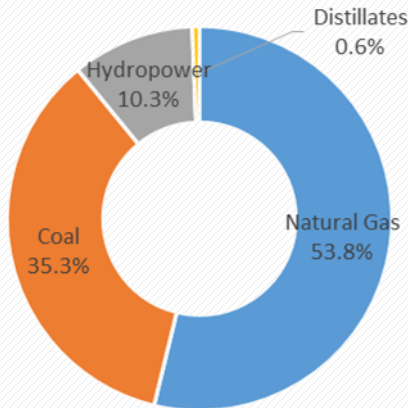
Process Window Simulation

Note:

1. The architecture proposal is developed base on benchmarking exercise with selected automotive welding factories in Malaysia
2. The upgrading proposal is not limited to welding equipment only, but covers all manufacturing elements that may enhance quality & productivity in factory

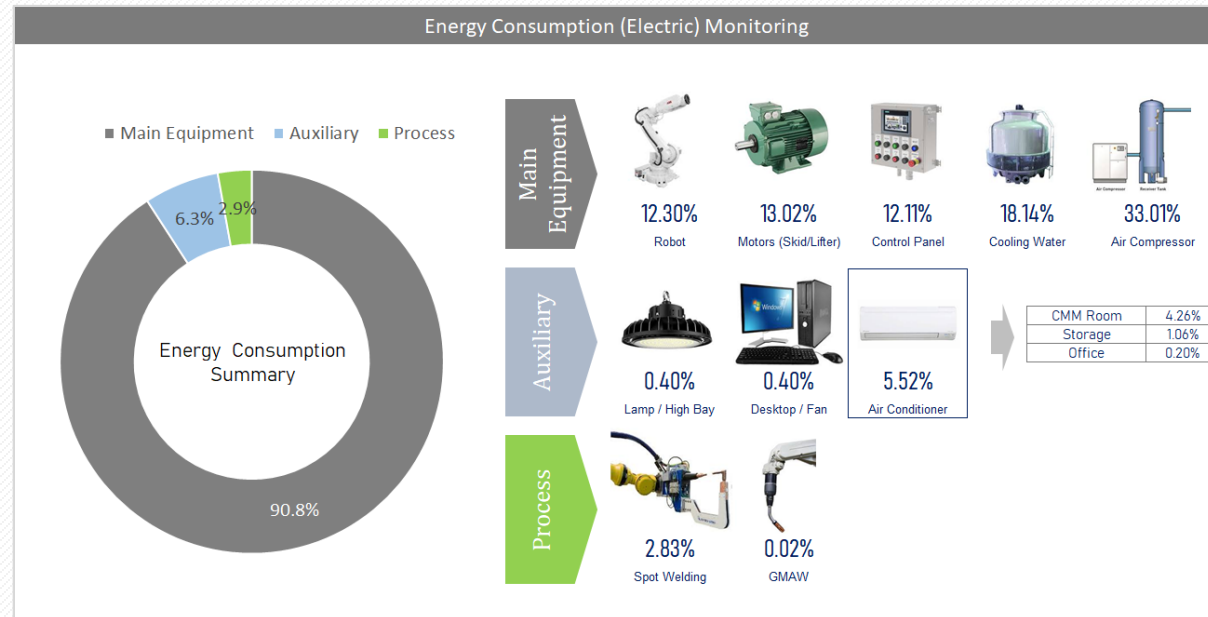
Case Study

Electricity Generation in Malaysia 2014



In this study, the actual energy consumption data for 3 months are given by Plant Facilities, and then to be compared with established formula / calculation to predict each single equipment energy consumption at welding shop. Then, this calculation can be used to evaluate future welding shop energy consumption for upcoming project. Moreover, by evaluating every single equipment or tool, the highest energy consumption equipment can be identified and further improvement can be made. This is very important so that new welding shop will be energy efficient and low cost in operation.

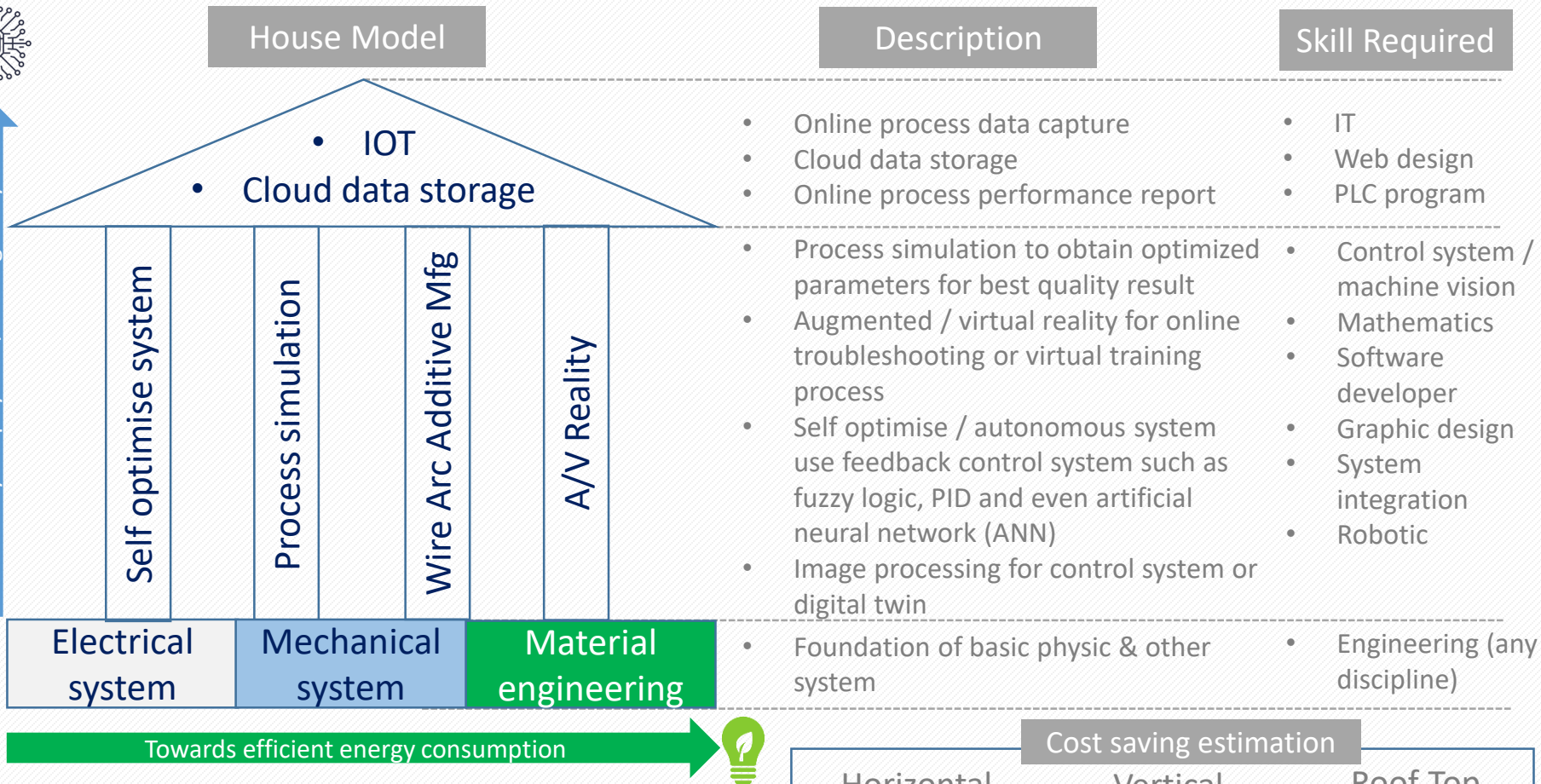
In modern manufacturing practice, energy consumption is getting more and more concern by automotive car manufacturers due to the constantly increasing energy cost and to the ecological burden related to the energy production and use. The great use of electrical energy for industrial operations is responsible for significant CO2 emissions and thus, climatic changes. According to the data from Tenaga National annual report 2014, 53.8% of the electricity generation is met by natural gas, 35.3% is met by coal, 10.3% by hydropower and 0.6% by distillates. Therefore, higher the energy requirement for manufacturing processes, higher the electrical energy generation required. Hence, higher CO2 emission rate since most of electricity generation are met by natural gas & coal.



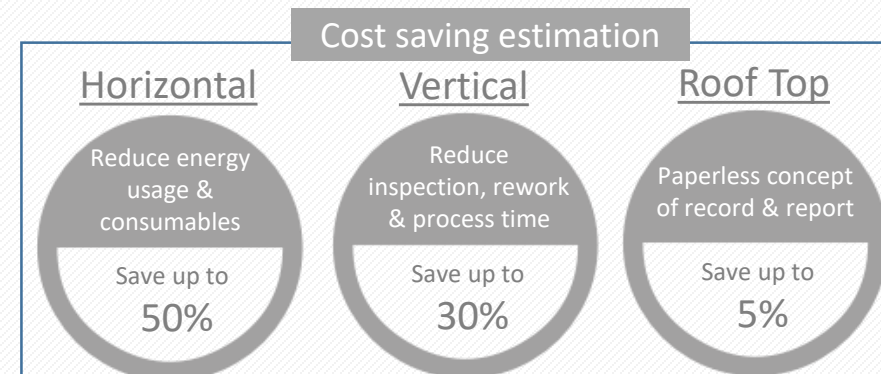
Model Proposal



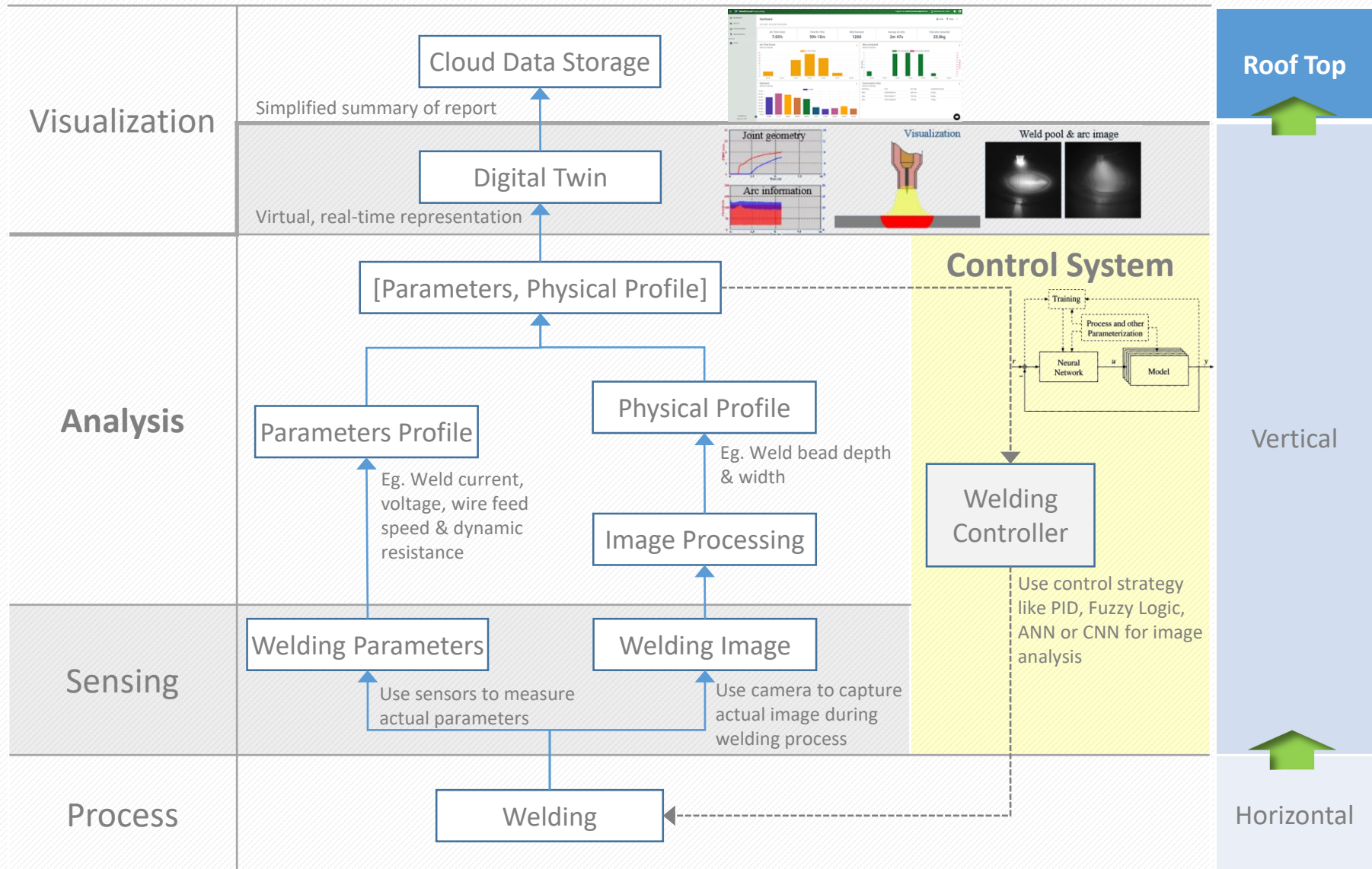
Towards cyber physical / intelligent system

**Notes:**

1. House model for complete system presentation is proposed as general concept of horizontal – vertical integration of a system inline with IR 4.0
2. Horizontal axis represents the basic / foundation of engineering disciplines that the revolution is more towards efficient energy consumption
3. Vertical axis represents system upgrading towards cyber physical and IOT system
4. The cost saving estimation is based on case study of spot welding system



Simplified Model



Case Study

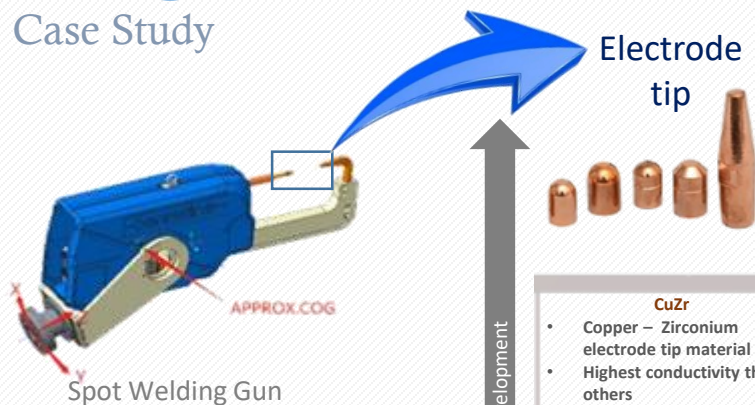
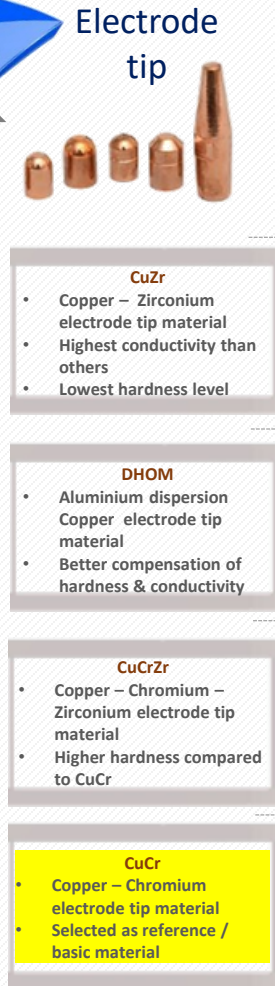


Table 1 : Electrode Tip Specification

RWMA Class	Type of Material	Hardness, HRB	Conductivity, IACS %
Class 1	CuZr	70	90%
Class 2	CuCr	78-87	78% - 85%
	CuCrZr	85-92	50% - 70%
Class 20	CuAl ₂ O ₃	80-90	72% - 80%
Class 3	CuBe	93-105	45% - 60%

*IACS – International Annealed Copper Standard

Towards complex Copper Alloy electrode tip development



Energy Efficient Matrix

Towards better energy efficiency



29%

31%

44%

26.5%

29%

41%

24%

26%

37%

24%

26%

37%

TYPICAL AC GUN

- Separate gun – transformer configuration
- Transformer freq : 50 Hz
- Energy efficiency : 24%

AC TRANS-GUN

- Combined gun – transformer configuration
- Transformer freq : 50 Hz
- Energy efficiency : 27%

MFDC TRANS-GUN

- Combined gun – transformer configuration
- Transformer freq : 1000 Hz
- Energy efficiency : 37%

Towards energy efficient Welding Transformer

Notes:

- X - axis represents welding transformer's revolution towards energy efficiency improvement
- Y - axis represent electrode tip material development to enhance it conductivity & hardness towards better energy efficient & prolong lifespan
- The matrix shows the energy efficiency value as a results transformer & electrode tip combination

Welding Technology : Vertical – Horizontal Integration (Spot Welding)

Case Study

AUTONOMOUS CAR
(ANALOGY)

SELF OPTIMISE PROCESS
(SPOT WELDING)

Welding Transformer vs Control System Matrix



Welding Transformer vs Control System Matrix		
		✓
		✓
✓	✓	✓
TYPICAL AC GUN <ul style="list-style-type: none"> Separate gun – transformer configuration Transformer freq : 50 Hz Energy efficiency : 24% 	AC TRANS-GUN <ul style="list-style-type: none"> Combined gun – transformer configuration Transformer freq : 50 Hz Energy efficiency : 27% 	MFDC TRANS-GUN <ul style="list-style-type: none"> Combined gun – transformer configuration Transformer freq : 1000 Hz Energy efficiency : 37%
Towards energy efficient Welding Transformer		

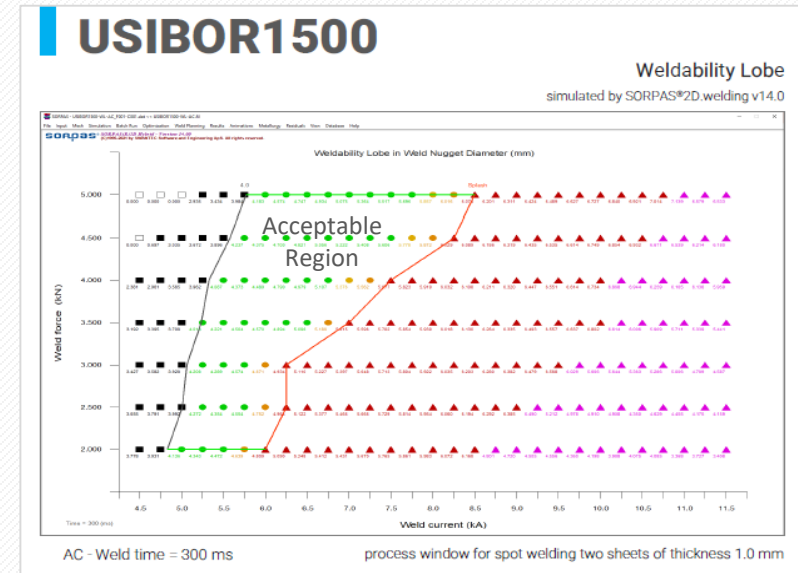
Notes:

1. X - axis represents welding transformer's revolution towards energy efficiency improvement
2. Y - axis represent welding control strategy towards self optimization process, which is inline with level of autonomous car
3. The innovation of spot welding transformer is directly proportional to the development of welding control system

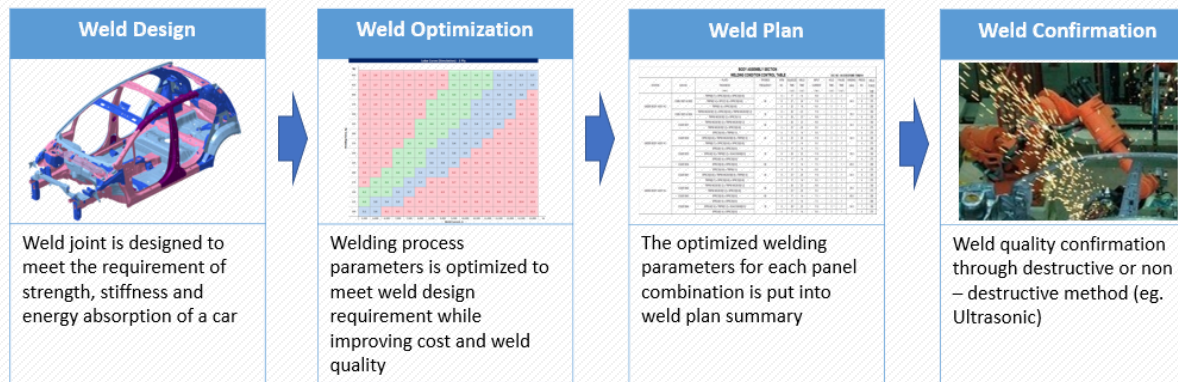
Welding Technology : Welding Simulation in Automotive Industry

In modern welding activities in automobile manufacturing industry, the welding simulation software is widely used to select the best parameters that meet the manufacturer's requirement especially on joint strength. The main feature that very useful for optimization process is process window (weldability lobe) simulation function.

Weldability lobe is defined as a graphical presentation represent the range of acceptable welding parameters set that may results in acceptable weld qualities. The region inside the curve for both graphs are 'acceptable' weld region according to design requirements. The main purpose to simulate the weldability lobe is to identify the optimized process window of welding parameters to achieved desired spot weld quality while reducing operational cost especially on welding power consumption and consumables.



Process Window Simulation by SORPAS

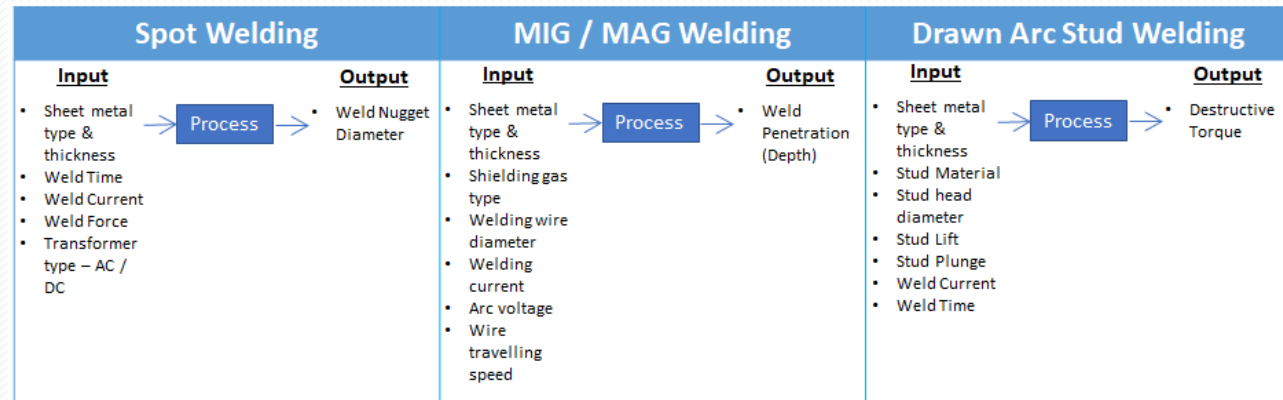


Welding Parameters Setting Process Flow

Process optimization using process window simulation is highly recommended to avoid repetitive task of physical welding confirmation process as a result of bad welding parameters setting. This will definitely reduce lead time to set correct welding parameters for each automotive body panel combination. Other than optimization process, this process window also can be used to understand the impact of process inputs to the final output (in this case, weld nugget diameter) when varying it process inputs

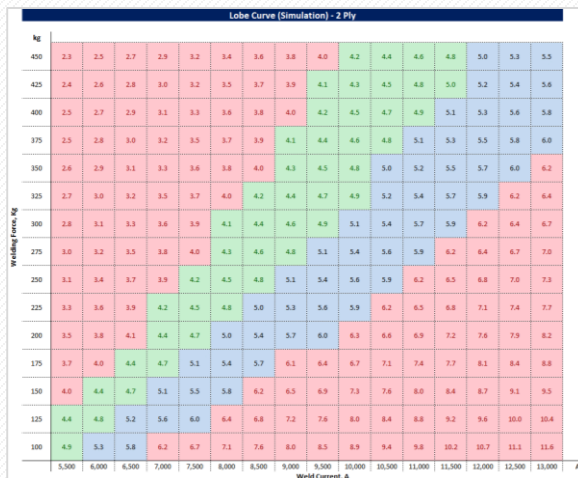
Case Study

Developing process window simulation for automotive use is a practical decision when considering cost effective and its usage since this simulation is only to be used during production development stages. The principle of process window simulation for any welding type is still the same, but the only difference is the inputs considered in the process and the desired output that to be estimated. Then, a mathematical modelling is developed for each welding process.

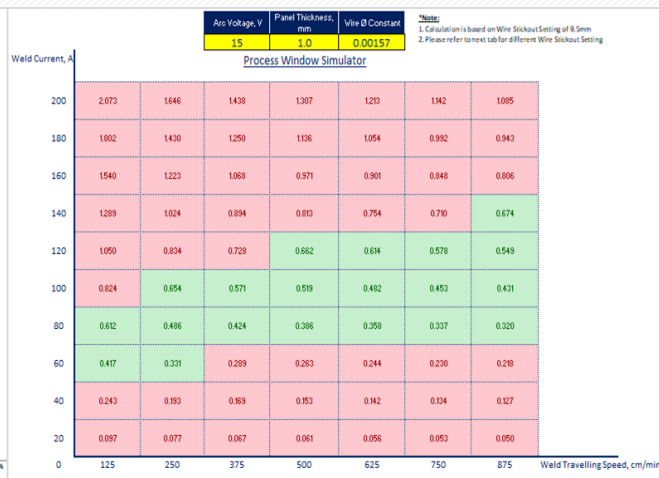


Sample of Process Input & Output for Mathematical Modelling Development

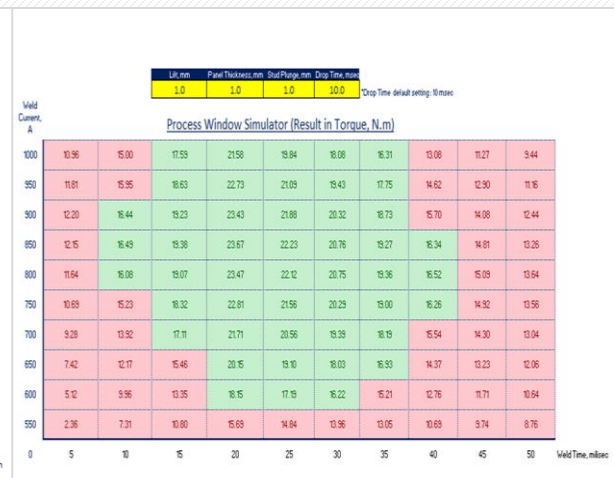
The mathematical model or equation from each welding process is then programmed to generate weldability lobe (process window) in 2D form. The generated graph may also help engineer or technician to directly see the impact when varying process input parameters. This will guide them for fine tuning the parameters to get desired output.



Process Window Simulation (Spot Welding)



Process Window Simulation (MIG Welding)



Process Window Simulation (Stud Welding)



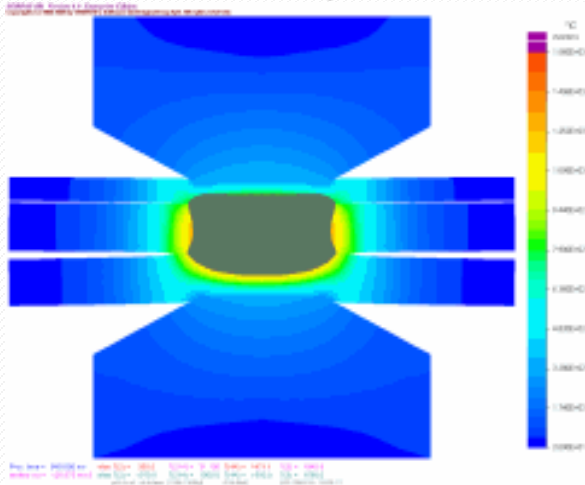
Welding Technology Implementation

- Adaptive Spot Welding System
 - Introduction to Spot Welding
 - Revolution of Spot Welding System
 - Process Simulation for Spot Welding
 - Adaptive Spot Welding Control System
- GMAW Welding Technology
 - Introduction to GMAW Welding Process
 - Shielding Gas Impact on GMAW
 - Process Simulation for GMAW
- Non Destructive Weld Testing Method

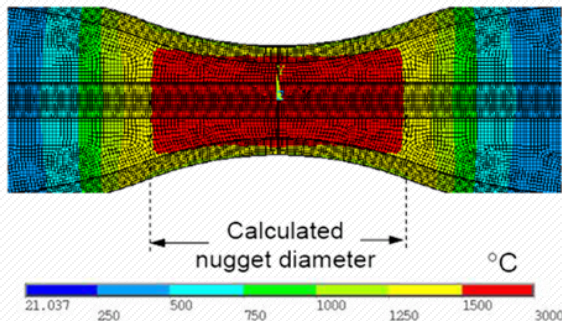


Basic Information

Spot Welding Process



Weld Nugget Formation



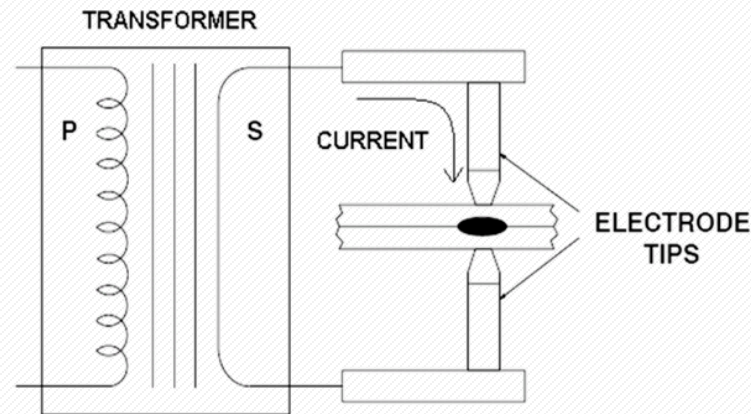
Definition:

The process of permanently joining two or more metal parts, by melting both materials. The molten materials quickly cool, and the two metals are permanently bounded

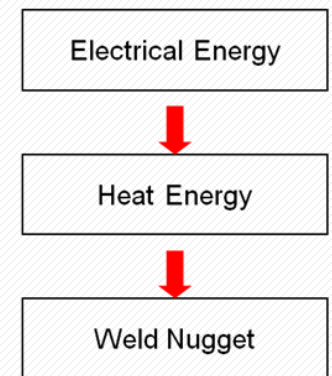
Description:

The heat used for welding is generated by passing current through a resistive circuit. It is electrical property of *Resistance* to the flow of the current through the metal that causes heat to be generated when the current flows through it.

Typical Flow Diagram:



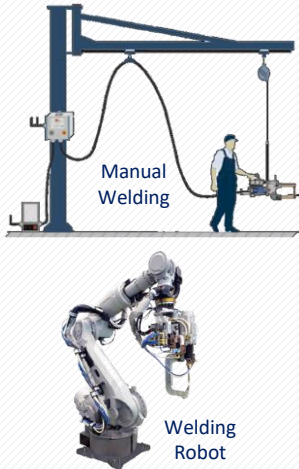
Typical Process Flow



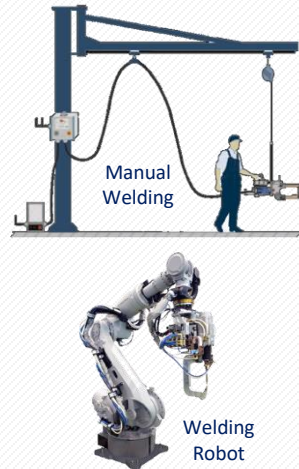
Spot welding Method:

- Manual (Man)
- Automatic (Robot)

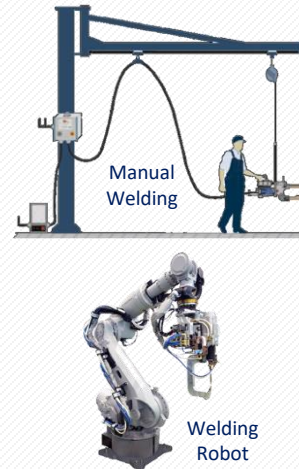
AC Welding



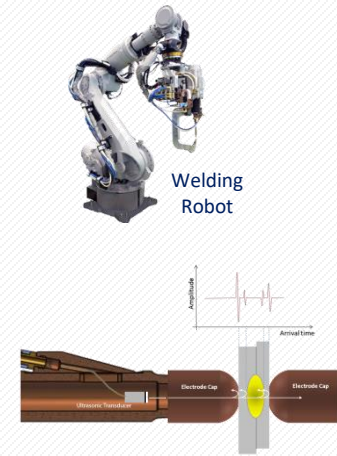
DC Welding



DC Welding with Adaptive System



Adaptive DC Welding with RIWA



Revolution of Spot Welding System

AC Spot Welding

- Energy efficiency value of 24% to 27 % results in higher welding current & longer weld time required to achieve desired weld nugget diameter
- Open loop system (No feedback system)

DC Spot Welding

- Mid Frequency DC transformer direct attach to welding gun with frequency of 1000Hz
- Energy efficiency value of 37% results in lower welding current & shorter weld time required to achieve desired weld nugget diameter
- Open loop system (No feedback system)

Adaptive DC Spot Welding

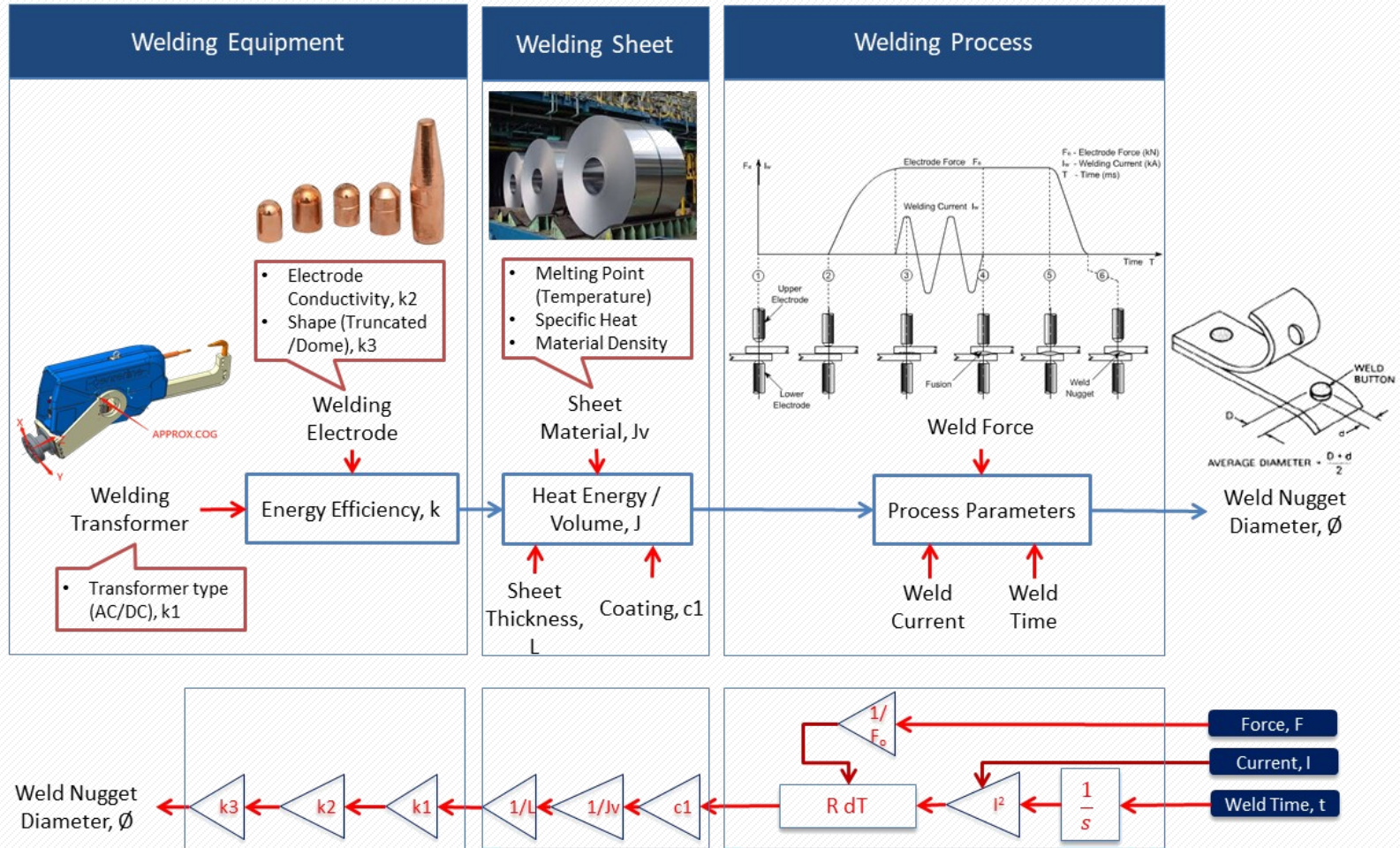
- Mid Frequency DC transformer direct attach to welding gun with frequency of 1000Hz
- Energy efficiency value of 37% results in lower welding current & shorter weld time required to achieve desired weld nugget diameter
- Closed loop / feedback system
- Adaptive system compensates any disturbance during welding process..ie worn out tip, dirt, small gap..etc to achieve desired weld nugget diameter
- Use process resistance curve as reference for the controller to automatically adjust welding parameters

Adaptive DC Spot Welding with RIWA

- RIWA – Real time Integrated Weld Analyzer (Ultrasonic device capable of measuring spot weld size right after the weld is produced)
- Integration of Adaptive MFDC with RIWA may reduce or eliminate offline spot weld size quality confirmation, resulting less welding inspector required at production line

Case Study

Resistance Spot Welding – Welding Process Block Diagram & Modelling

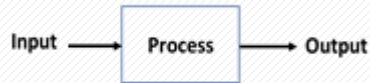


In the case of modelling spot welding process, 3 main blocks of inputs are considered – welding process parameters, sheet metal specification and type of welding gun. Each chosen input parameter is tested to confirm its significant impact to process window simulation.

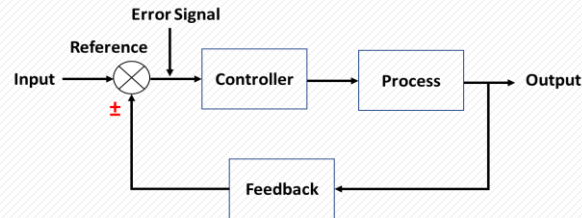
An Introduction

System Model

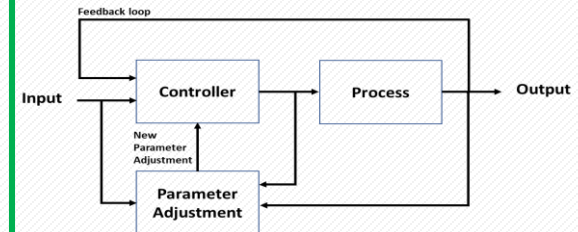
❑ Open-loop system



❑ Closed-loop system



❑ Adaptive Closed-loop system



Application Sample

❑ No Cruise Control

- 100% human control
- Driver need to shift gear up – accelerate
- Driver have to brake - decelerate / stop



❑ Conventional Cruise Control

- Set at desired speed – move at constant speed (pedal off).
- Machines monitor & warn driver if any obstacle ahead.
- Driver have to break – decelerate / stop.



❑ Adaptive Cruise Control

- Machines monitoring, adapting to environment.
- Reduce speed according to safety distant.
- Accelerate back to set speed.



Adaptive control system is widely used especially in autonomous car development. Then, this technology is horizontally replicated to its associate sectors including automotive manufacturing processes.

Case Study

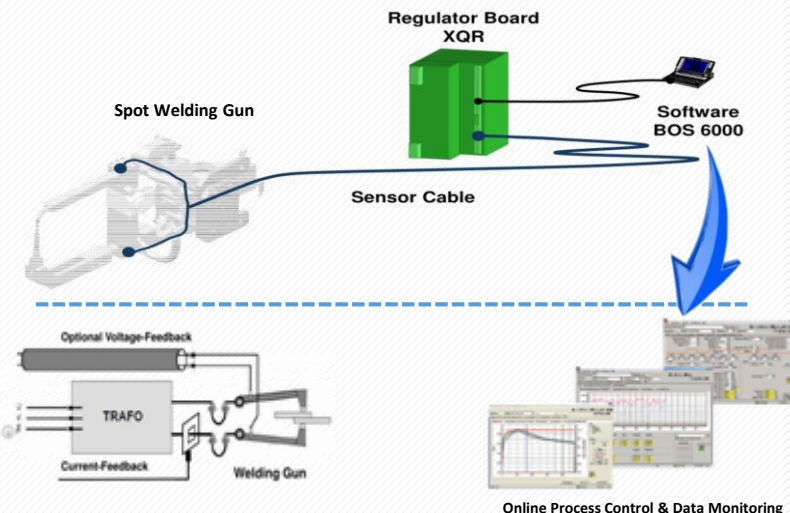
What is Adaptive system?

- A closed loop system that auto adjusted the parameters of controller to compensate any disturbances.

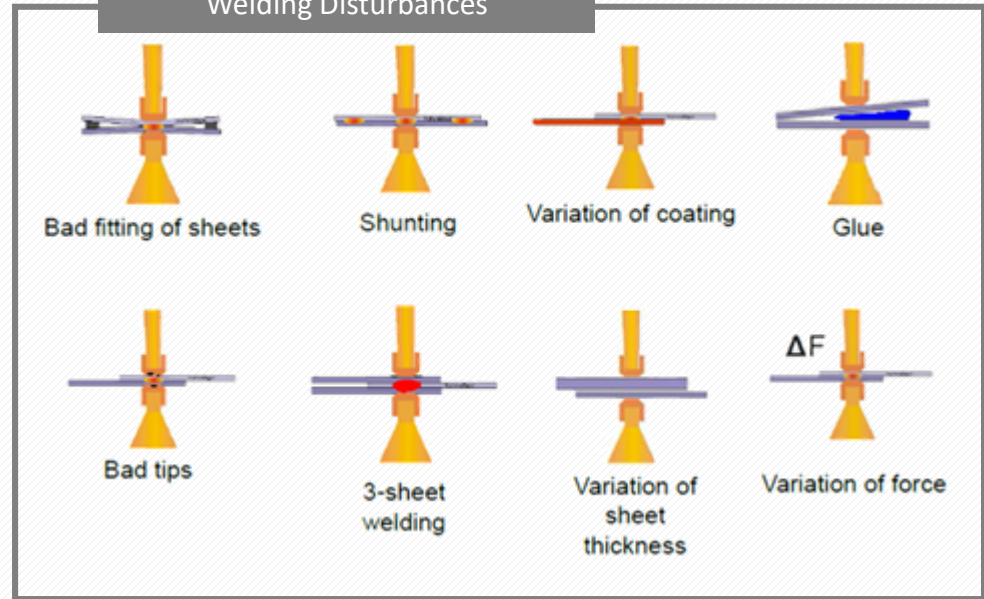
Why using Adaptive system?

- It adjust welding parameters, in real time, so every weld is performed within the tightest quality tolerances.

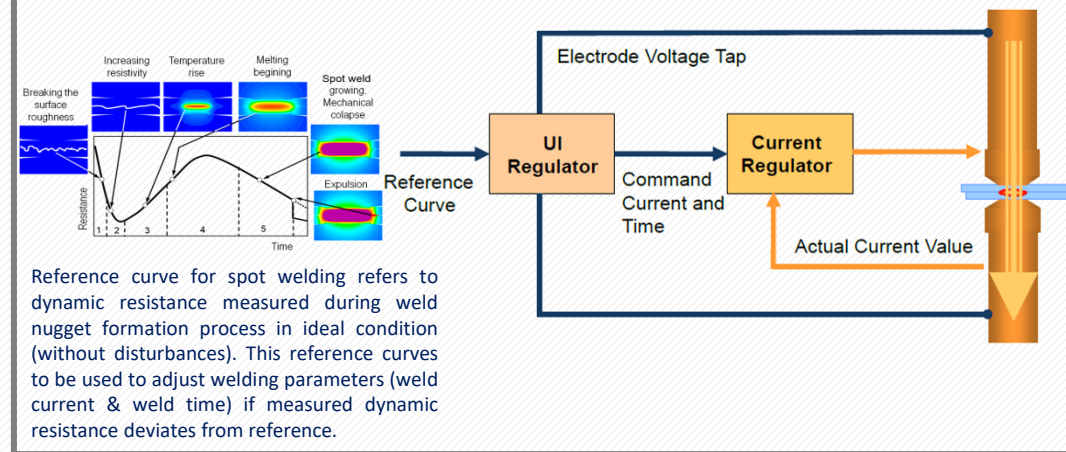
Adaptive System Configuration



Welding Disturbances

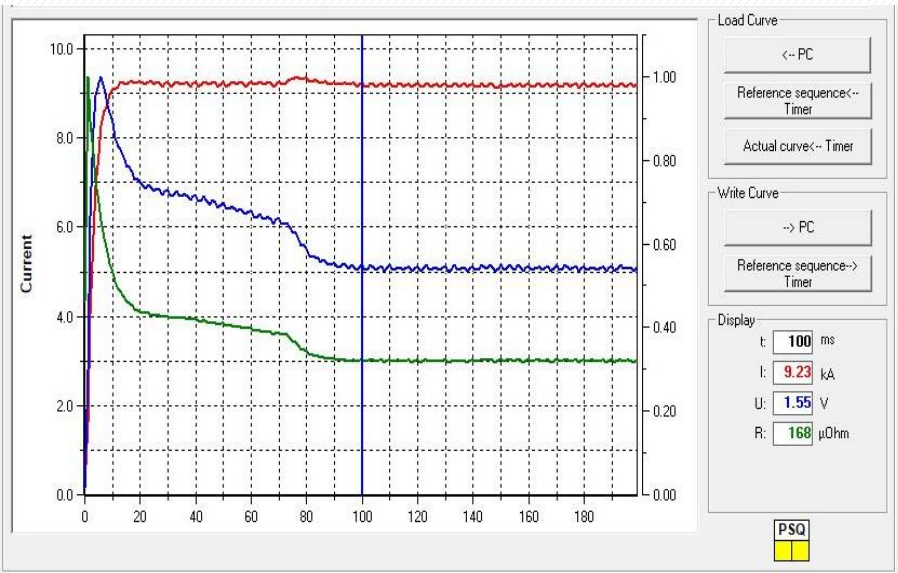


Spot Welding Control System

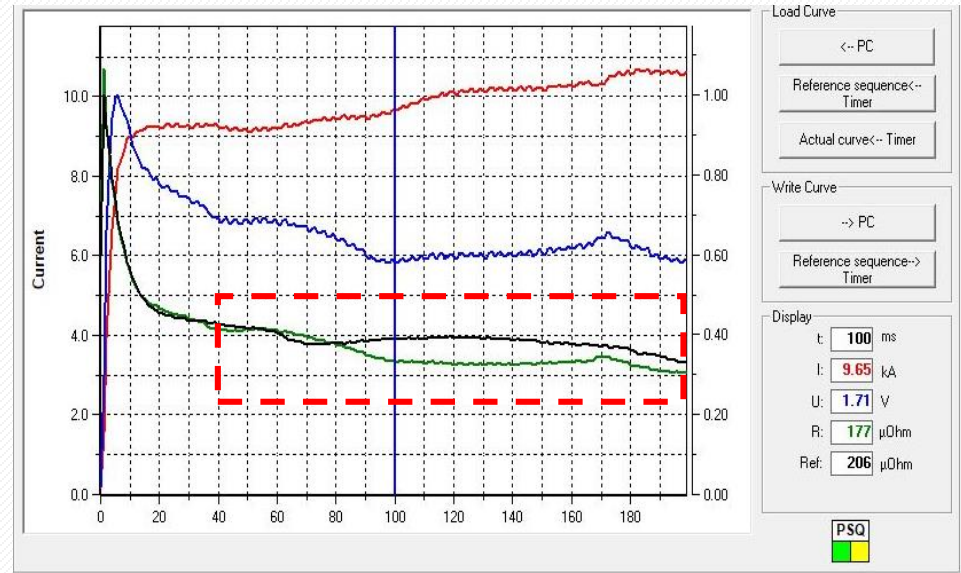


RESULTS AND ANALYSIS

Test 1 : Tip $\varnothing 6$ after tip dress + 90° perpendicular to test piece with **sealant existed** between the panel.



ADAPTIVE OFF



ADAPTIVE ON

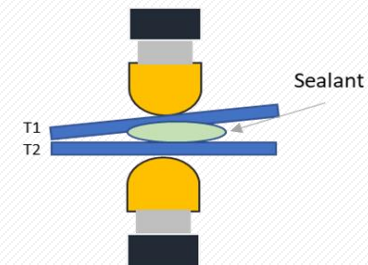
Result - Weld Nugget Diameter (mm)

Reference	Simulation	Adaptive OFF	Adaptive ON
6.2	6.6	4.1	5.5

Base on experimental result, the weld nugget formation when activating adaptive control system is much better than normal mode and closer to reference. Weld current automatically adjusted after 60 msec of welding process to compensate disturbance (in this case, sealant).

Red: Current (I)
Green: Resistance (R)

Blue: Voltage (V)
Black: Ref. Resistance (R)

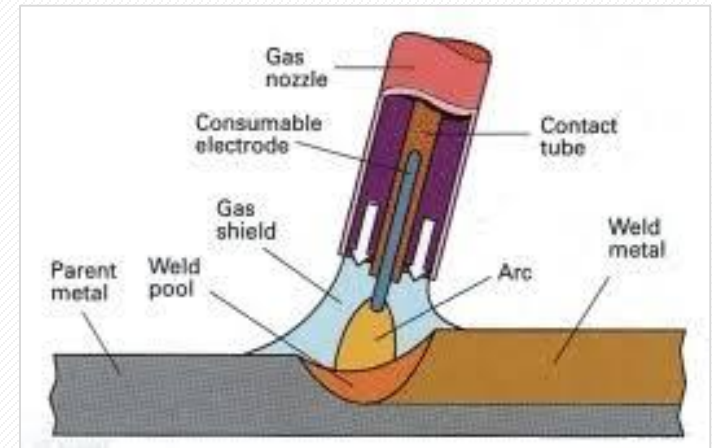


Basic Information

Gas Metal Arc Welding

Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) and metal active gas (MAG) is a welding process in which an electric arc forms between a consumable MIG wire electrode and the workpiece metal(s), which heats the workpiece metal(s), causing them to fuse (melt and join). Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from atmospheric contamination.

https://en.wikipedia.org/wiki/Gas_metal_arc_welding



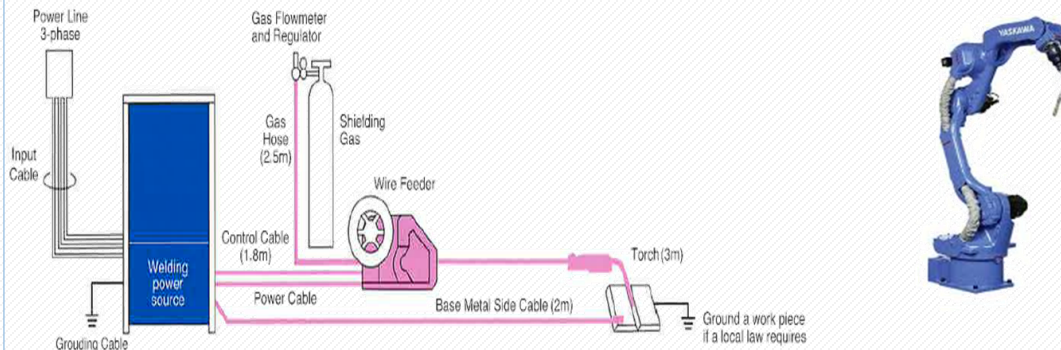
<https://youtu.be/twUAa5LWUvk>

Manual Welding Machine

OTC XD 350S (Daihen)

Robotic Welding Machine

MotoWeld RL 350 (Yaskawa / Motoman)



Shielding Gas	Mix 82% Argon, 18% CO2
Welding Wire Size	Ø 1.0mm
Special Function	Depth / penetration control (compensate low skill worker / poor programming)

GMAW Equipment Setup

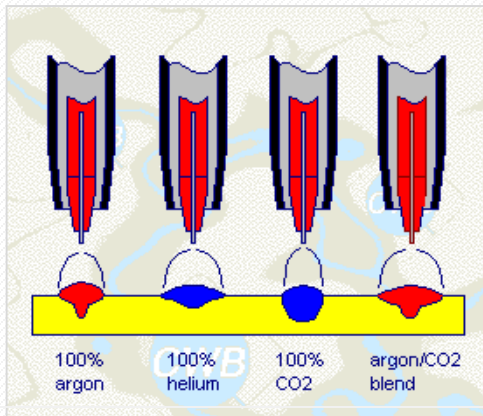
Gas Metal Arc Welding Principles

- GMAW is approximately 92% - 98% efficient
- GMAW requires a shielding gas
- The primary **function** of **shielding gases** is to protect (**shield**) the molten weld metal from contact with the atmosphere, thereby avoiding the formation of oxides of the metal.
- CO2 and argon - CO2 mixtures are known as metal active gas (MAG) processes

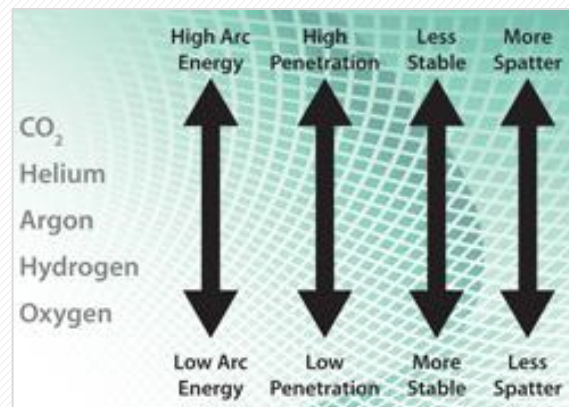
Basic Information

Items		Shielding Gas			Remarks
		Argon, Ag	Mix (Ag + CO ₂)	Carbon Dioxide, CO ₂	
Quality	Spatter	Low	Medium	High	• Post weld cleaning frequency is high as spatter produced high
	Weld Penetration	Low	Medium	High	
	Weld Strength	Low	Medium	High	• Base on shear strength test result
	Arc Stability	High	Medium	Low	• Weld bead weave level
Power Consumption	Arc Energy	Low	Medium	High	• For CO ₂ , high current setting required to get good quality result (arc stability)
Cost	Cost / Cylinder	High	Medium	Low	

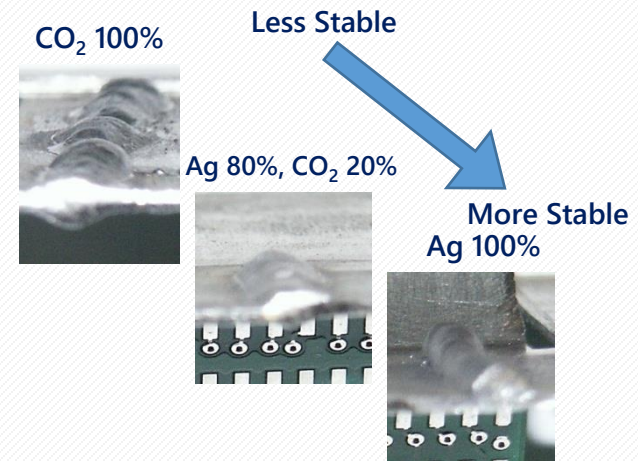
Note : 1. Shielding gas that currently used at Welding shop is mix of 82% Argon & 18% CO₂
 2. Argon is use for 'fillet' weld (ferrous metal)



WELD PENETRATION PROFILE



SHIELDING GAS MATRIX



ARC STABILITY

Non – Destructive Welding Quality Inspection Method

Method	Destructive (Body Destructive / Test Piece)	Non – Destructive Test (NDT)	
		Driver Check	Ultrasonic (A/C - Scan)
Accuracy	99%	20% to 40%	95%
Disadvantages	<ul style="list-style-type: none"> • Lost a unit body per activity (Body In White) • Require a lot of manpower & times during activities • Destructive peel method 	<ul style="list-style-type: none"> • Cannot detect small weld nugget / nugget size (diameter) • May cause flange / panel wavy after driver check been done 	<ul style="list-style-type: none"> • High investment on equipment



Ultrasonic Spot Weld Analyser

