# Application of response surface methodology for optimization of fiber laser welding of stainless steel 316 L

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**INFLPR**

**Center for Advanced Laser Technologies**

**CETAL**


# University of Ljubljana
## Faculty of Mechanical Engineering

# Short Term Scientific Mission:

## Comparative study of welding stainless steel and aluminium alloys using fiber lasers and disk lasers

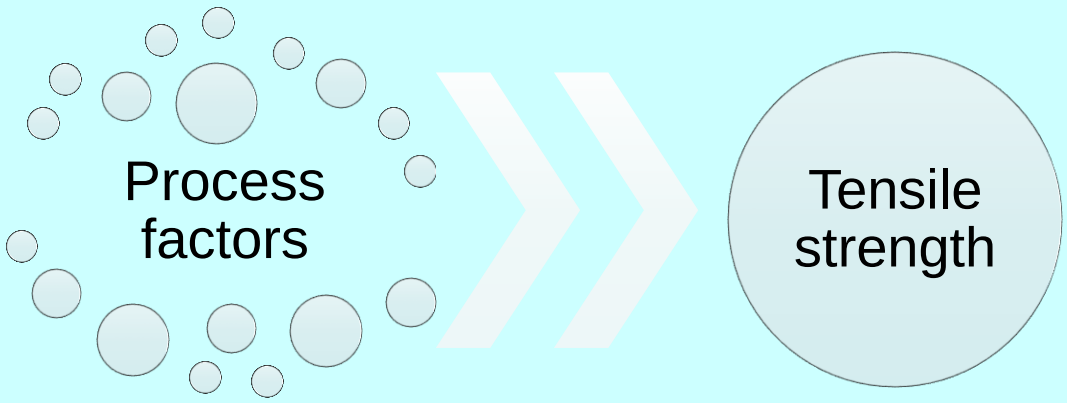
- Prepare the samples by laser cutting (Romania, before STSM)
- Laser butt welding of stainless steel 316 L and aluminium 1050 using 1030nm wavelength disk laser with a power up to 3 kW continuous wave (Romania, before STSM)
- Laser butt welding of stainless steel 316 L and aluminium 1050 using a single mode fiber laser, 1070 nm wavelength with a power up to 400 W, continuous wave (Slovenia, during STSM)
- Dissimilar laser welding of stainless steel 316 L and aluminium 1050 in lap joint configuration using a single mode fiber laser, 400 W power, continuous wave (Slovenia, during STSM)

# Content

- Introduction
- Experimental set up
  - Materials
  - Tests procedures
  - Response surface methodology
- Results and discussions
  - *Analysis of front weld width*
  - *Analysis of middle weld width*
  - *Analysis of opposite weld width*
  - *Analysis of tensile strength*
  - *Optimization of the process parameters*
- Conclusions

# Introduction

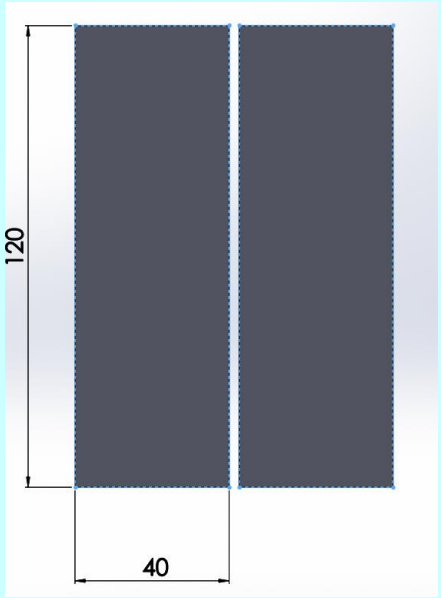
Laser butt welding of stainless steel 316L was investigated using remote laser welding system with 400 W continuous wave fiber laser. The effect of welding speed (0.5 to 2.9 m/min) and focusing position (-2 to 2 mm) on the front weld width, middle weld width, back width, and tensile strength (Rm) were examined using response surface methodology (RSM).

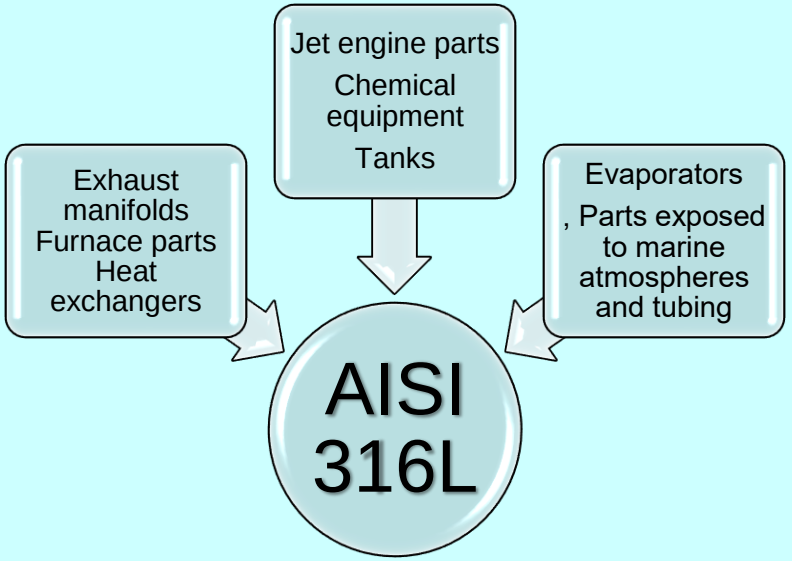



Optimize Goal

# Experimental set up
# Materials

Austenitic stainless steel EN 1.4404 (AISI 316L)
Rectangular specimens with dimensions: 40 × 120 × 1 $mm^3$

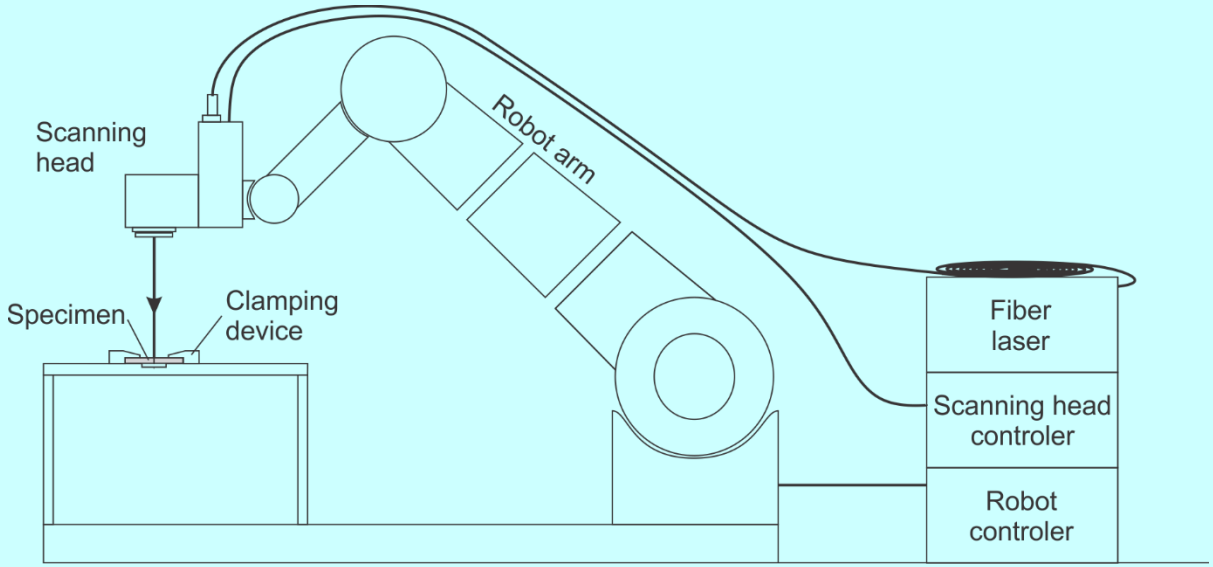


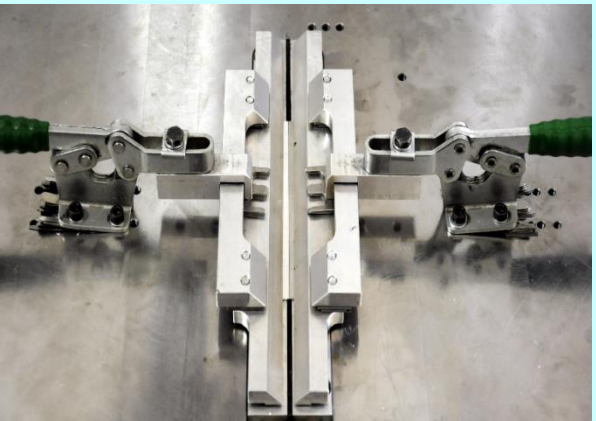




| Factor | Name | Units | Low | High |
|---|---|---|---|---|
| A | Welding speed | m/min | 0.5 | 2.9 |
| B | Focus position | mm | -2 | 2 |

Laser beam welding variables

# Experimental set up
# Laser remote welding system

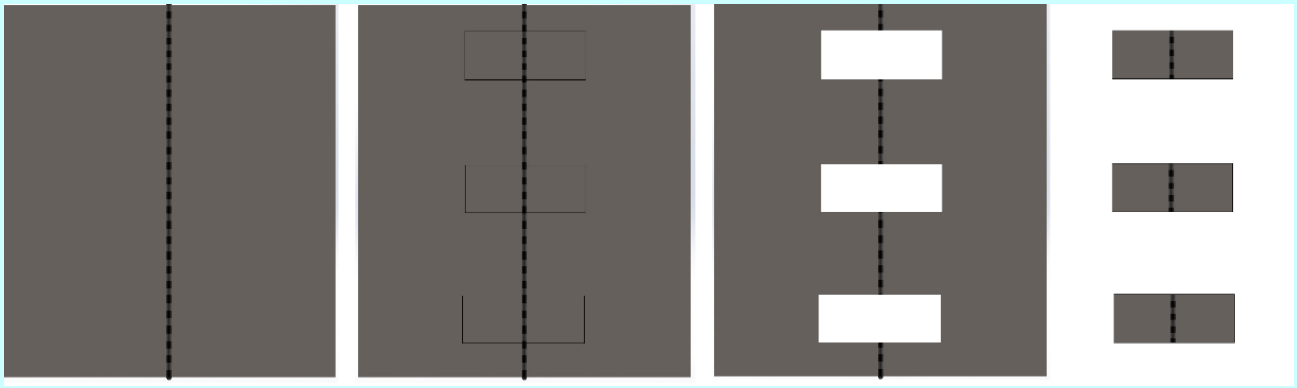


A single mode fiber laser
(IPG Photonics, model YLR-400-AC)
Three-dimensional scanning head
(HighYAG, RLSK)
Six-axis robot arm
(Motoman MC2000)

# Experimental set up
# Tests procedures

Schematic representation of the specimens after cutting



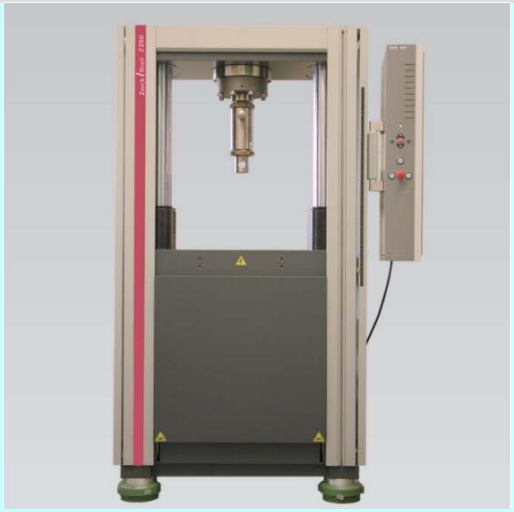
Grinding

Polishing

Etching

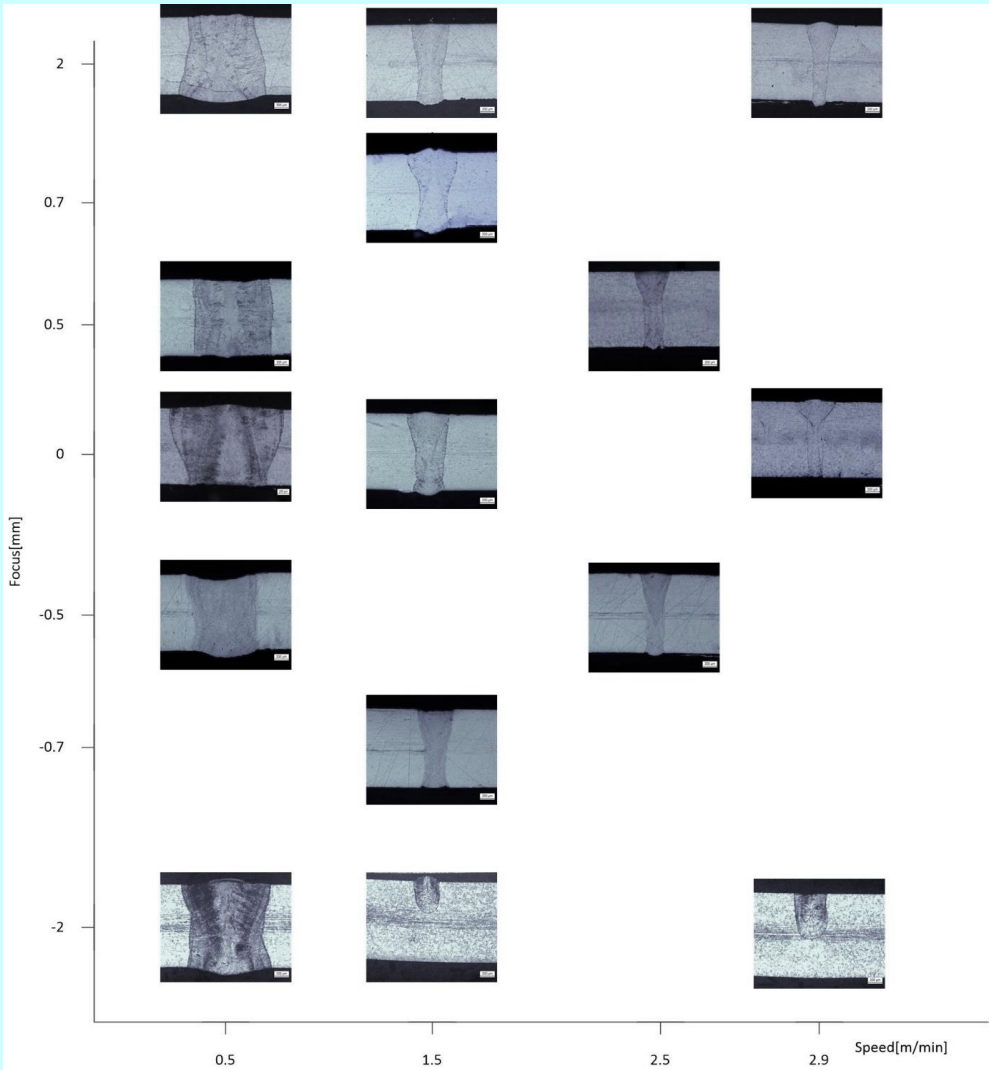
# Results and discussions

Tensile test machine Zwick Z250



Olympus Inverted Metallurgical Microscope GX 51

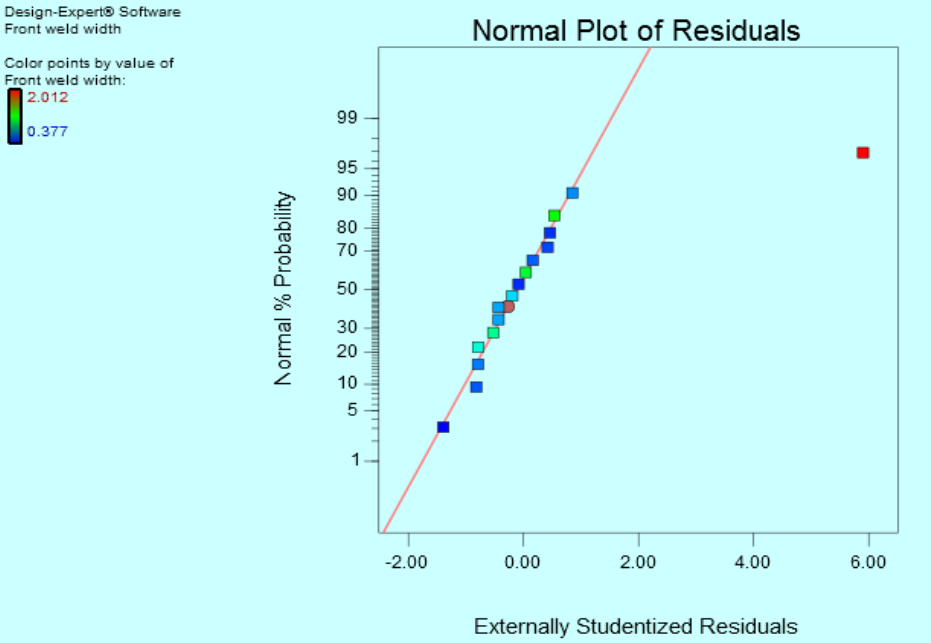
ImageJ software ⇒ Measure the weld width



# Results and discussions

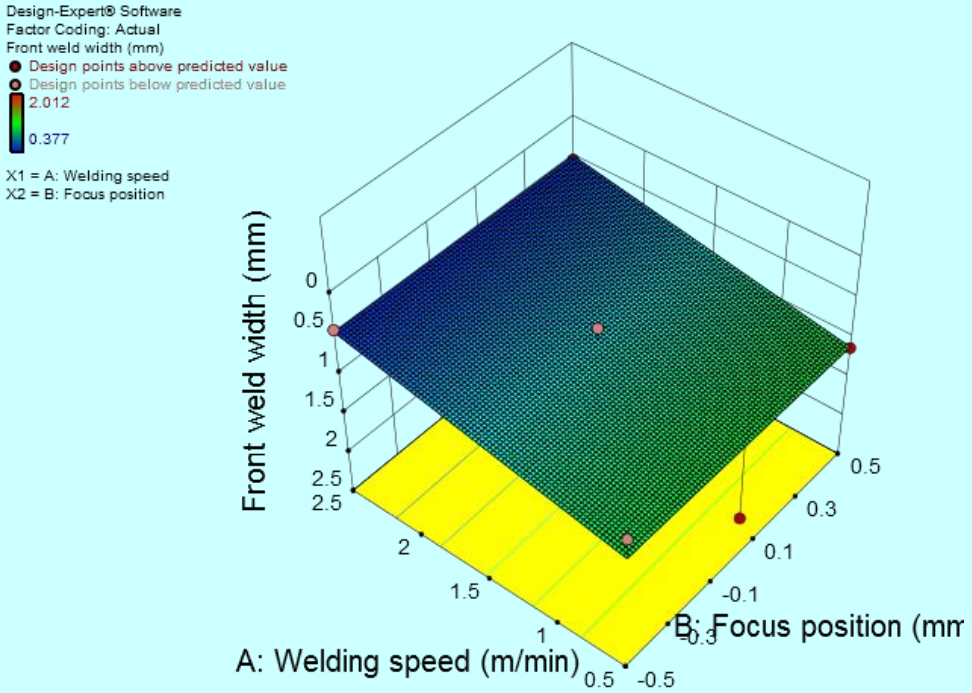
*Analysis of front weld width*

The fit summary for front weld width suggests the linear model




Normal probability plot

3D surface plot

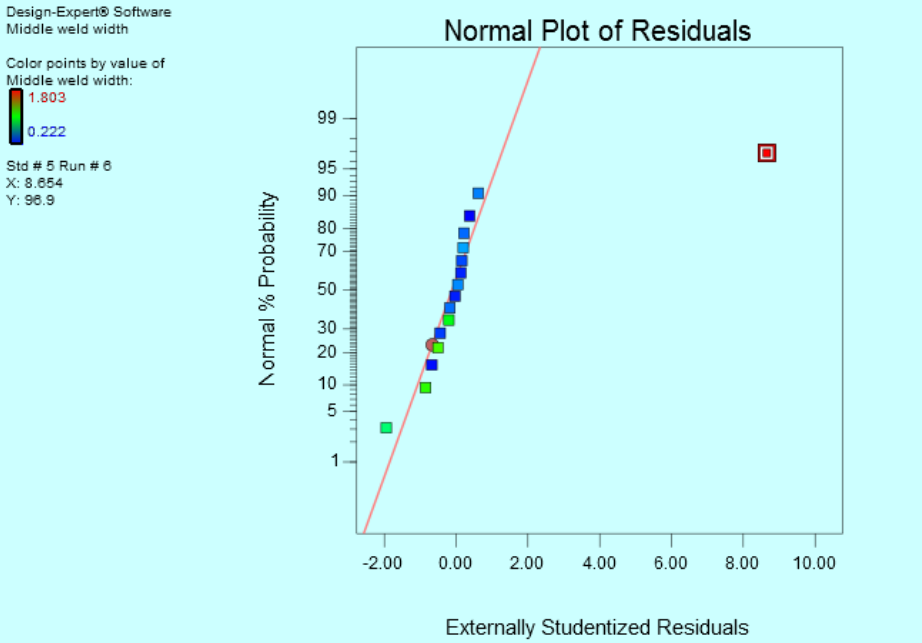



$F_w$ = 1.243 – 0.306 * Ws + 0.011 * Fp

# Results and discussions

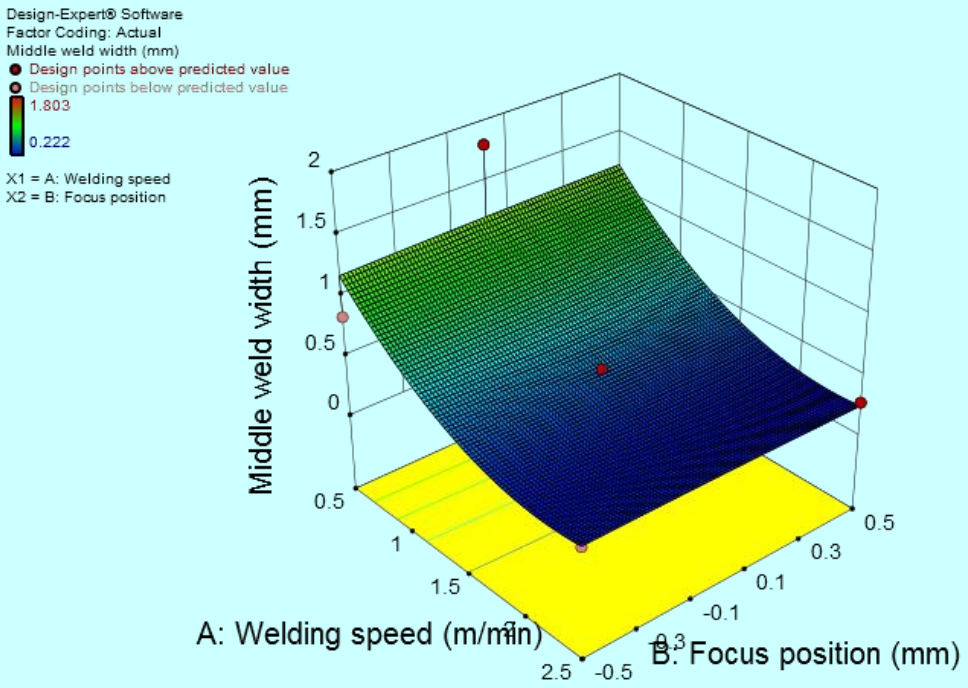
*Analysis of middle weld width*

The fit summary for middle weld width suggests the quadratic model




Normal probability plot

3D surface plot

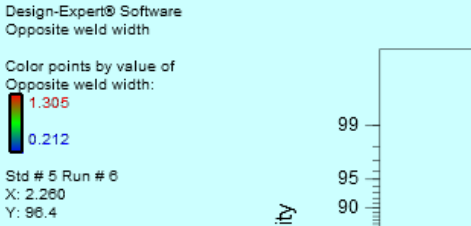


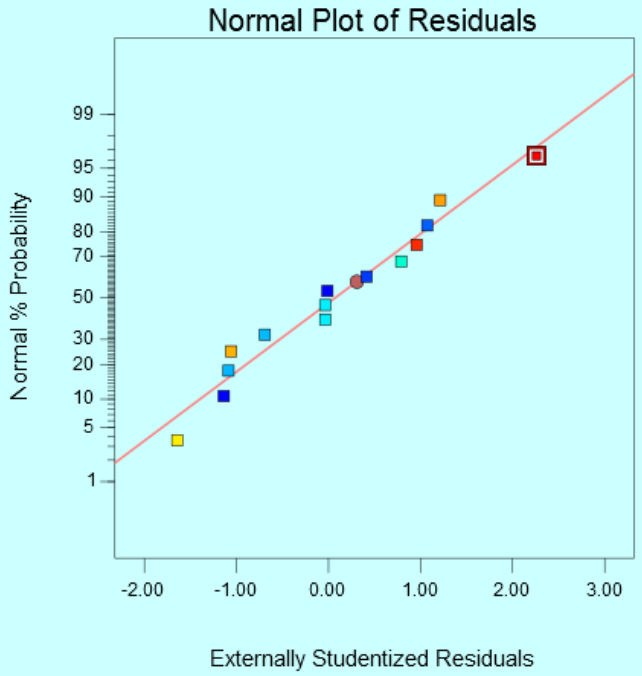

$$M_w = 1.825 - 1.385 * W_s + 0.066 * F_p - 0.037 * W_s * F_p + 0.304 * Ws^2 - 0.026 * Fp^2$$

# Results and discussions

*Analysis of opposite weld width*

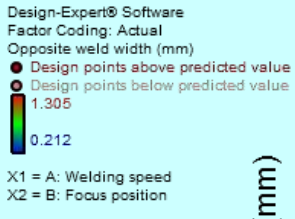
The fit summary for opposite weld width suggests the quadratic model

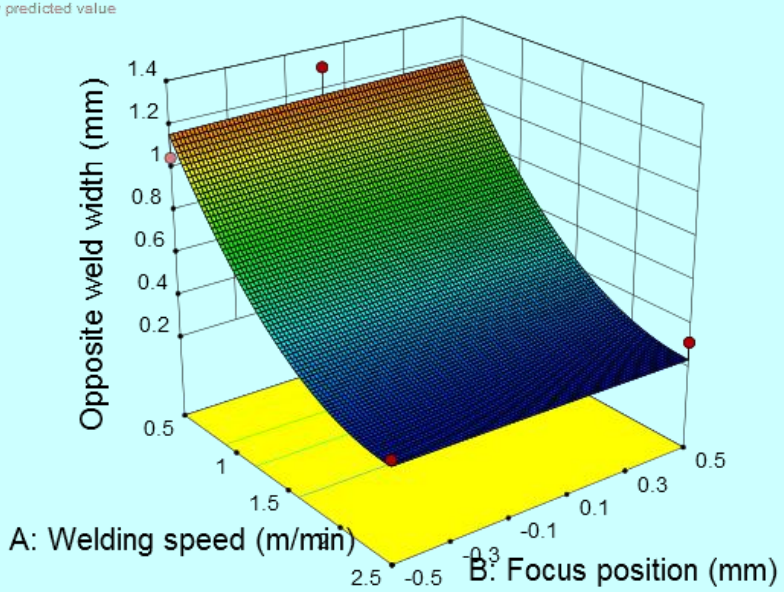



Normal probability plot

3D surface plot



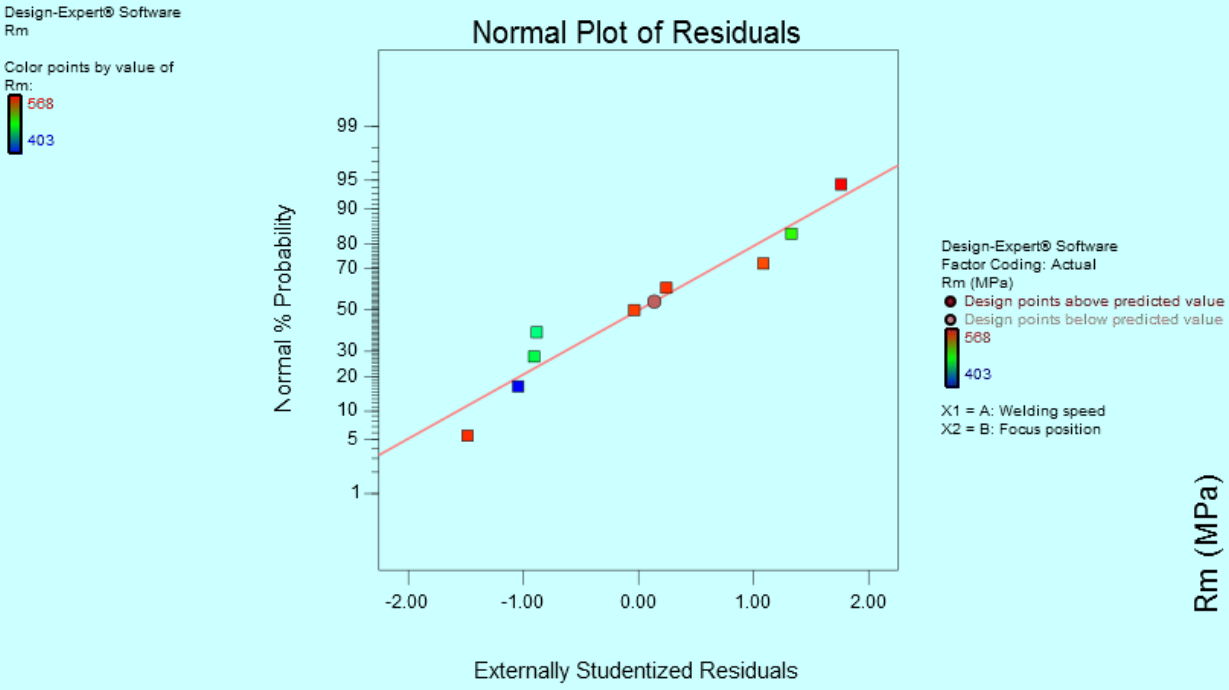




$O_w$= 1.7 -1.16*Ws + 0.041* Fp - 0.02 * Ws*Fp + 0.23* $Ws^2$ -0.003* $Fp^2$

# Results and discussions

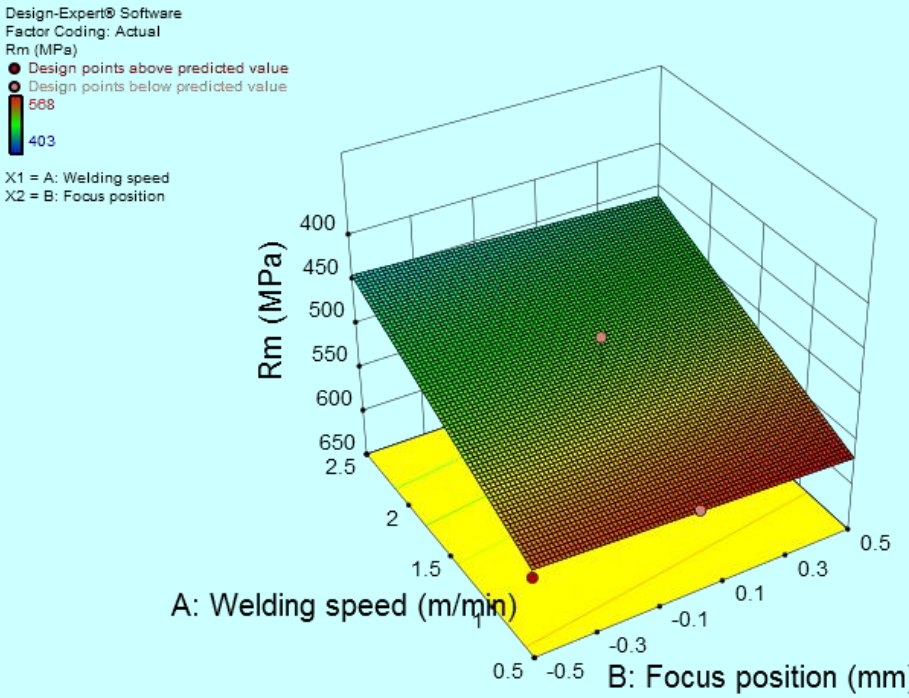
## *Analysis of tensile strength*

The fit summary for tensile strength suggests the linear model




Normal probability plot

3D surface plot




$R_m$= 586.163 -53.735 * $W_s$ + 15.652 * Fp

# Results and discussions

*Optimization of the process parameters*

## Optimal welding condition based on the first criterion

| Name | Goal | Lower Limit | Upper Limit | Importance |
|---|---|---|---|---|
| A:Welding speed | maximize | 0.5 | 2.5 | 3 |
| B:Focus position | is in range | -0.5 | 0.5 | 3 |
| Front weld width | minimize | 0.377 | 2.012 | 3 |
| Middle weld width | minimize | 0.222 | 1.803 | 3 |
| Opposite weld width | minimize | 0.212 | 1.305 | 3 |
| Rm | maximize | 403 | 568 | 5 |

# Results and discussions

*Optimization of the process parameters*

Solutions- First criterion

| No | Welding speed | Focus position | Front weld width | Middle weld width | Opposite weld width | Rm | Desirability | w/o Intervals |
|---|---|---|---|---|---|---|---|---|
| 1 | 2.071 | 0.500 | 0.614 | 0.251 | 0.279 | 482.698 | 0.732 | 0.763 |
| 2 | 2.081 | 0.500 | 0.611 | 0.249 | 0.277 | 482.183 | 0.732 | 0.763 |
| 3 | 2.062 | 0.500 | 0.617 | 0.252 | 0.281 | 483.212 | 0.732 | 0.763 |
| 4 | 2.084 | 0.500 | 0.610 | 0.249 | 0.276 | 482.005 | 0.732 | 0.763 |
| 5 | 2.052 | 0.499 | 0.619 | 0.254 | 0.283 | 483.676 | 0.732 | 0.763 |
| 6 | 2.110 | 0.500 | 0.602 | 0.246 | 0.271 | 480.616 | 0.732 | 0.763 |
| 7 | 2.252 | 0.491 | 0.558 | 0.235 | 0.248 | 472.828 | 0.727 | 0.761 |

# Results and discussions

*Optimization of the process parameters*

## Optimal welding condition based on the second criterion

| Name | Goal | Lower Limit | Upper Limit | Importance |
|---|---|---|---|---|
| A:Welding speed | Is in range | 0.5 | 2.5 | 5 |
| B:Focus position | is in range | -0.5 | 0.5 | 3 |
| Front weld width | is in range | 0.377 | 2.012 | 3 |
| Middle weld width | is in range | 0.222 | 1.803 | 3 |
| Opposite weld width | is in range | 0.212 | 1.305 | 3 |
| Rm | maximize | 403 | 568 | 5 |

# Results and discussions

*Optimization of the process parameters*

Solutions-Second criterion

| No | Welding speed | Focus position | Front weld width | Middle weld width | Opposite weld width | Rm | Desirability | w/o Intervals |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.949 | 0.500 | 0.651 | 0.273 | 0.308 | 489.245 | 0.569 | 0.615 |
| 2 | 1.938 | 0.500 | 0.654 | 0.275 | 0.311 | 489.827 | 0.569 | 0.615 |
| 3 | 1.960 | 0.500 | 0.648 | 0.270 | 0.305 | 488.657 | 0.569 | 0.616 |
| 4 | 1.999 | 0.500 | 0.636 | 0.263 | 0.295 | 486.561 | 0.569 | 0.616 |
| 5 | 2.032 | 0.500 | 0.626 | 0.257 | 0.287 | 484.800 | 0.568 | 0.616 |

# Conclusions

- The **welding speed** has the biggest influence on the **front** weld width.
- The results shows that the **welding speed** has negative influence on the **middle** and **opposite** weld width
- Butt weld strength suggests that both **welding speed** and **focus position** has effect on **tensile strength**.
- The optimal welding conditions that gives the **maximal welding speed** at **best joint tensile strength** were welding speed of~ 2.1 m/min and 0.5 mm laser beam focus position
- The optimal welding conditions that gives the **highest tensile strength** of 489 MPa and front weld width of 0.65 mm, middle weld width 0.27 mm and opposite weld width of 0.3 mm were the welding speed 1.9 m/min and focus position 0.5 mm above the surface of the workpiece

# Acknowledgements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Thank you for your attention!