PREDICTIVE CONTROL OF ALUMINUM WELD BEAD USING AN INFRARED THERMAL IMAGING WITH ARTIFICIAL INTELLIGENCE BASE METHOD

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PROJECT DAY 2024 FACULTY OF ENGINEERING

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BACKGROUND AND PROBLEM STATEMENT

Cracking in aluminum welds poses a major challenge in welding. This research integrates Machine Learning, Machine Vision, and welding technology to detect and predict these cracks, enhancing material quality and safety in various industries.

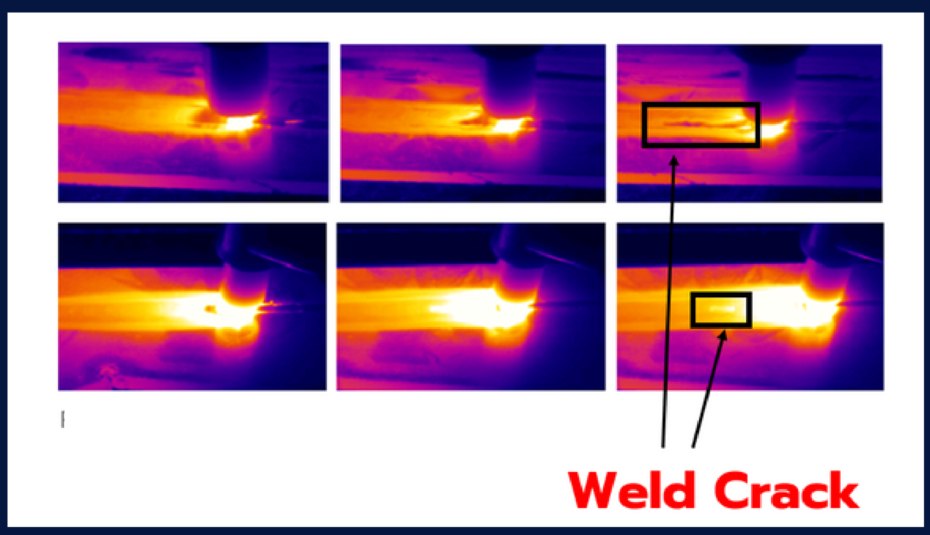
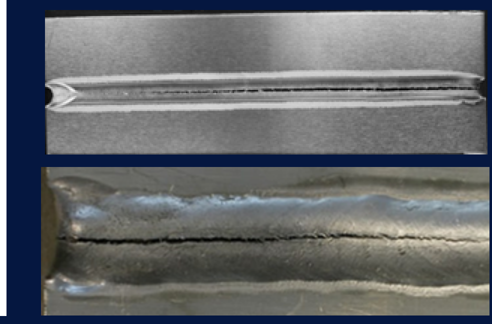


Image set of GTAW's welding thermal effect
[Quality inspection of welding seam in real-time with thermal imaging. by SAMK automation tutkimusryhmä (2014)]



Solidification Cracking

Automotive Welding in the Oak Ridge National Laboratory

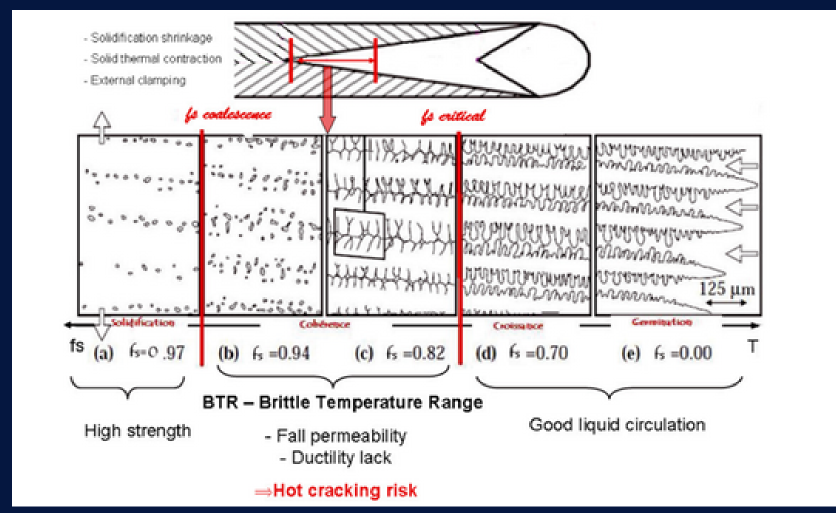


Figure shows evolution of the microstructure of mushy zone as function of temperature
[Effect of Weld Travel Speed on Solidification Cracking Behavior. Part 1: Weld Metal Characteristics (2020)]

EXPERIMENT AND RESULT

- **Data collection:**

Experiment setup for data collection

Using an infrared thermal camera for image acquisition of the specimen which had a thickness of 6 mm, a width of 40 mm, and a length of 125 mm. Operated by using the GTAW process the travel speed is controlled by an Industrial robot. Then, check the quality of the weld bead by liquid penetration test.

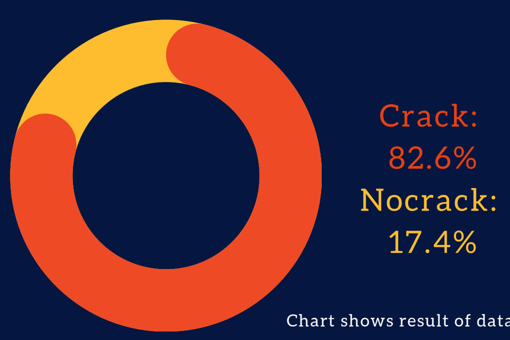
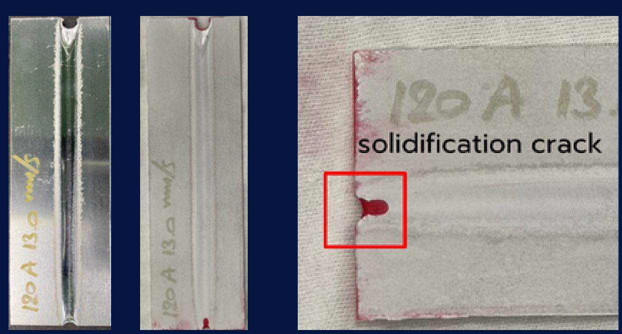


Chart shows result of data

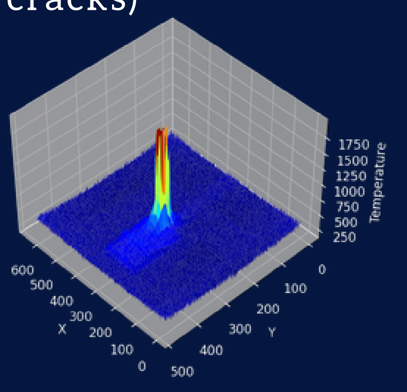


Weld solidification crack of Aluminum alloy tested by PT

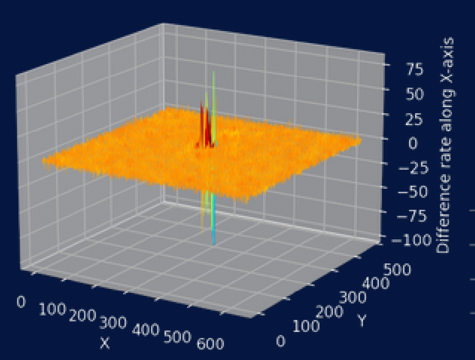
- **Crack detection algorithm:**

- After welding, image processing of specimens reveals cracks undetectable by regular images but clearly visible on thermal images

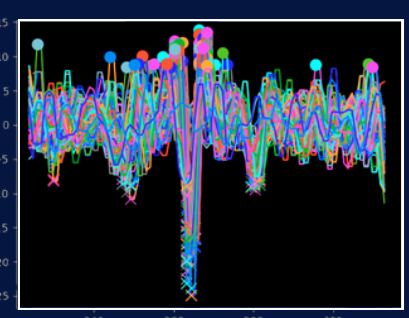
- Thermal image processing was developed to analyze the anomaly of the changing rate of temperature along the x-axis to detect cracks)



3D Surface of temperature Profile of a thermal picture frame during welding process

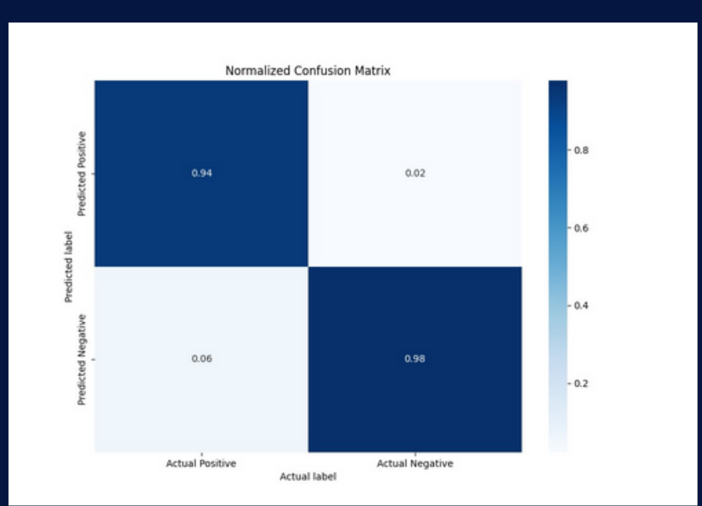


3D Surface of thermal difference rate along x-axis of the thermal picture frame

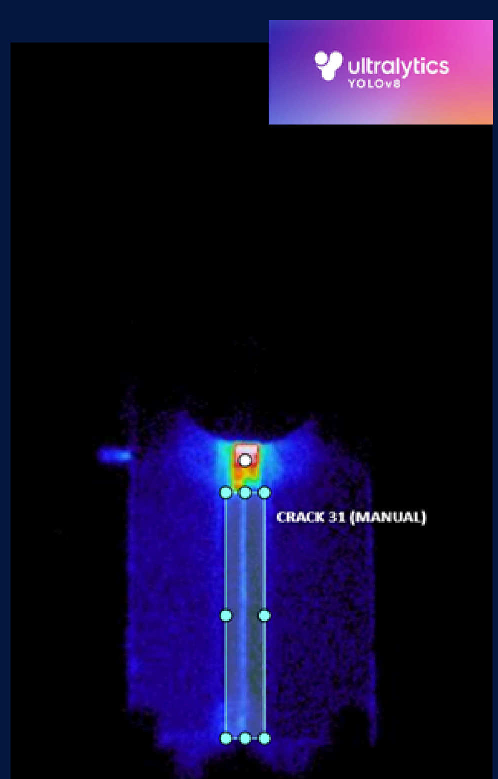


Relationship of thermal difference rate along x-axis of the thermal picture frame and x-axis

Finally, the machine-learning model was developed using a convolutional neural network (CNN) object detection to detect cracks in the training dataset of 5,778 thermal images(Crack = 2,889 images , no crack = 2,889



Confusion mtrix of the best model

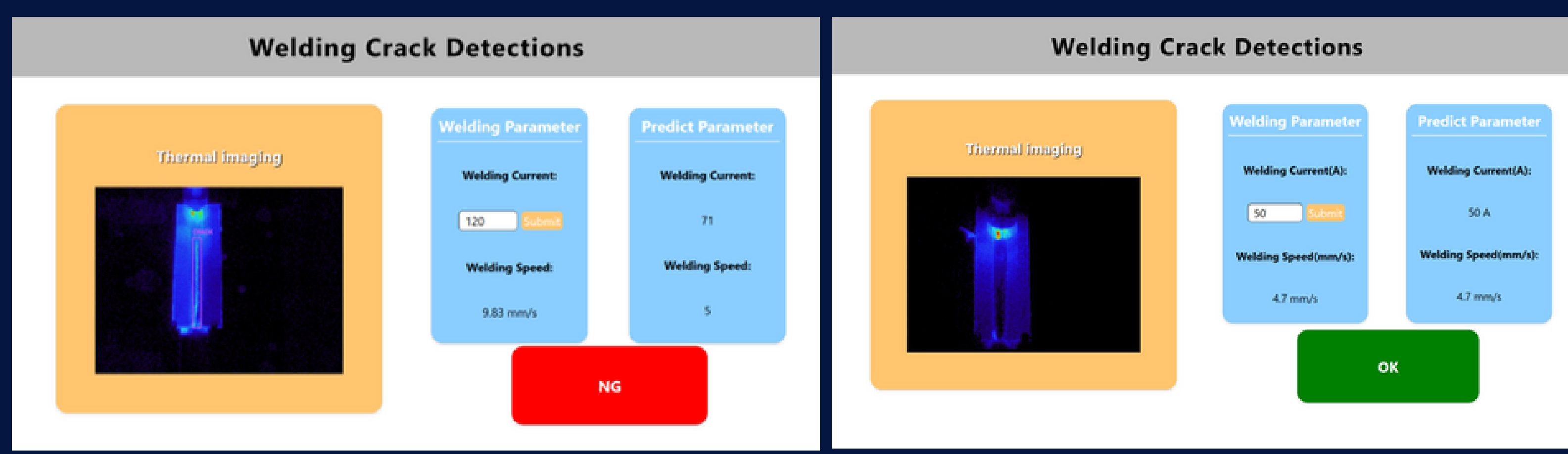


Example of training dataset using CVAT to annotate and YOLOv8 to train objectdetection model

PARAMETER PREDICTION

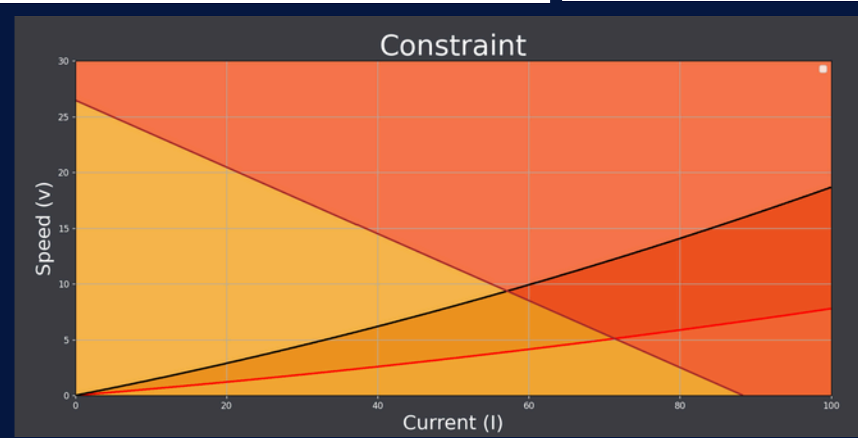
Welding parameters considered are input current (I) and travel speed (v). Constrained Optimization BY Linear Approximations optimizer is used.

User interface of the program



When crack detected

When no crack detected



Constraints are based on datasets of all conditions of current(I) in range of 30-160A and speed(v) in range of 2 - 16 mm/s

Graph shows the regions of constraints considered for optimizer

CONCLUSION

- **Crack detection algorithm:**

F1-SCORE

99.85% FOR TRAINING DATASET

AVERAGE IOU

75.03% FORTESTING DATASET

AVERAGE IOU

93.16% FOR TRAINING DATASET

A RAPID ANALYSIS SPEED OF

19.1 MILLISECONDS PER FRAME

F1-SCORE

95.86% FOR TESTING DATASET

- **Parameter prediction**

Reference Equation

$$H = (10 + 0.04I)\,\frac{I}{v}$$

H: Heat Input, I: Current, v: Speed

Linearized Equation

$$H(I,v) = (10I_0 + 0.04I_0^2)\frac{1}{v_0} + \left[\left((10 + 0.04I)\frac{1}{v}\right) \times (I - I_0)\right] + \left[\left((-10I - 0.04I^2)\frac{1}{v}\right) \times (v - v_0)\right]$$

I_0: Input Current, v_0: Input Speed, I: Optimized Current, v: Optimized Speed

$$\textit{Objective function}: \textit{Minimize}(\Delta H)$$

$$\textit{Subject to}\quad \frac{(10I+0.04I^2)}{v} \leq 180,\ \frac{(10I+0.04I^2)}{v} \geq 75,$$

$$0.05447I + 0.18189v - 4.81386 \leq 0$$

Consequently, this endeavor not only presents a swift and accurate crack detection solution but also holds potential as a guideline for implementation in industrial production systems

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- Effect of Weld Travel Speed on Solidification Cracking Behavior. Part 1: Weld Metal Characteristics (2020)A. Niel,a, F. Deschaux-beaume, C. Bordreuil, and G. FrasLaboratoire de Mecanique et de G ´ enie Civil LMGC- UMR5508, Univertsit ´ e Montpellier 2, Montpel- ´lier, France