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Nano-Tec™ Ceramic Welding Materials

-Material Development

-Lab Testing

-Field Trials

Example Exothermic Reaction & Materials Used

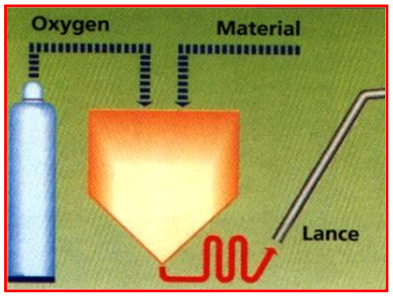
Metal + Oxygen = Metal Oxide + Heat

$Si + O_2 = SiO_2$ ⟹ ~910 kJ/mole (862 BTU/mole)

$4Al + 3O_2 = 2Al_2O_3$ ⟹ ~1675 kJ/mole (1,590 BTU/mole)

Materials Used in Ceramic Welding Process:

- Varies with type of substrate:
  - AZS
  - SILICA
  - FUSED SILICA
  - ZIRCON
  - SUPER DUTY ALUMINA
  - FUSED ALUMINA



- Materials are matched to the parent refractory
- The selection of equipment can affect weld quality.

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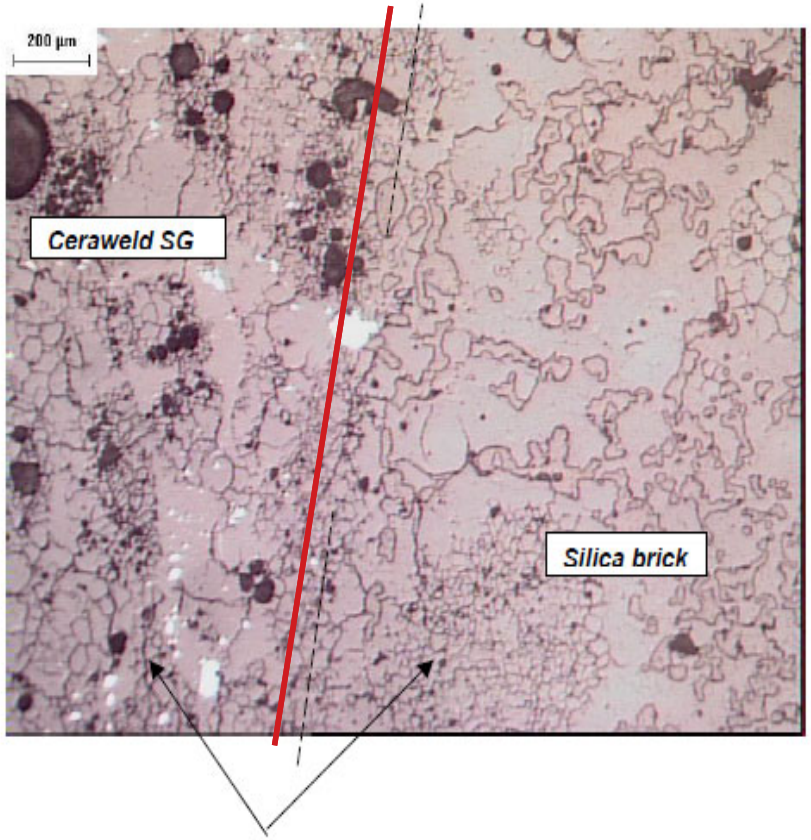
Substrate & Weld Mass Microstructure

SG Material



Cristobalite typical
"fish-scale" texture

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Introducing: Nano-Tec™

Nano-Tec™

Fosbel's Innovation to Providing Higher Yield Ceramic Welding Materials

The Welding Process

0.002s: The time it takes a particle to travel from the lance to the wall

During this time period the following has to occur:

- **Vaporize the metallic fuel**
- **Ignite the metallic vapor.**
- **Transfer the energy**
- **Melt / soften the particles before reaching the surface.**

Developing Nano-Tec™ Materials

Objective:

- **Maximum the energy extracted from metallics.**
- **Balance the energy generation with absorption.**
- **Minimize partially oxidized metallics.**
- **Maximize yield.**

Developing Nano-Tec™ Materials

Results:

Maximize the energy extracted from metallics.

- Average particle size reduced by 45%
- Surface area per unit mass increased 80%

Balance the energy generation with absorption.

- Surface area of aggregates decreased 20%
- Fuel/Ceramic surface area ratio increased 120%

Minimize partially oxidized metallics.

- Combustion efficiency increased by 65%

Maximize yield.

- Yield increased 15-18%

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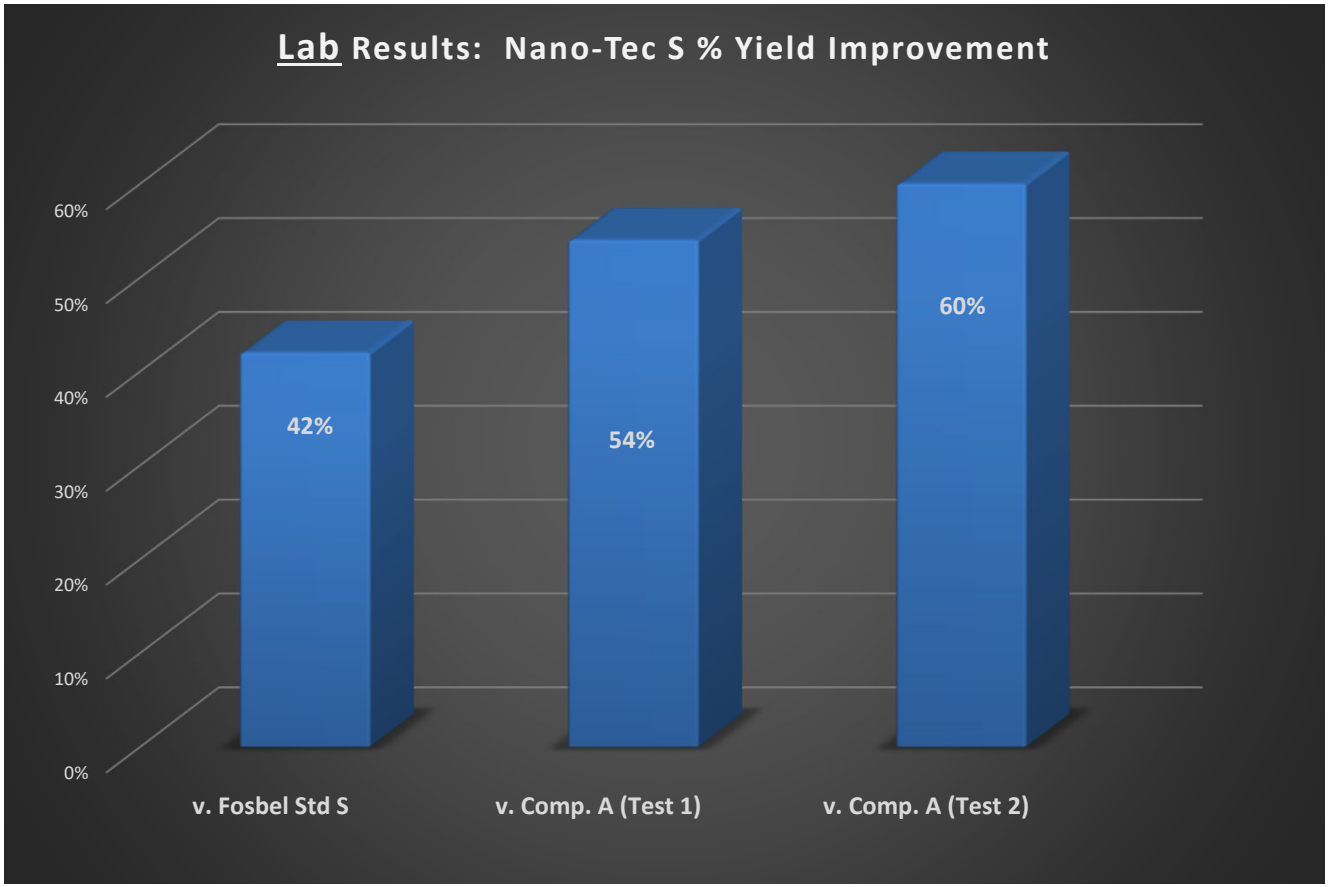
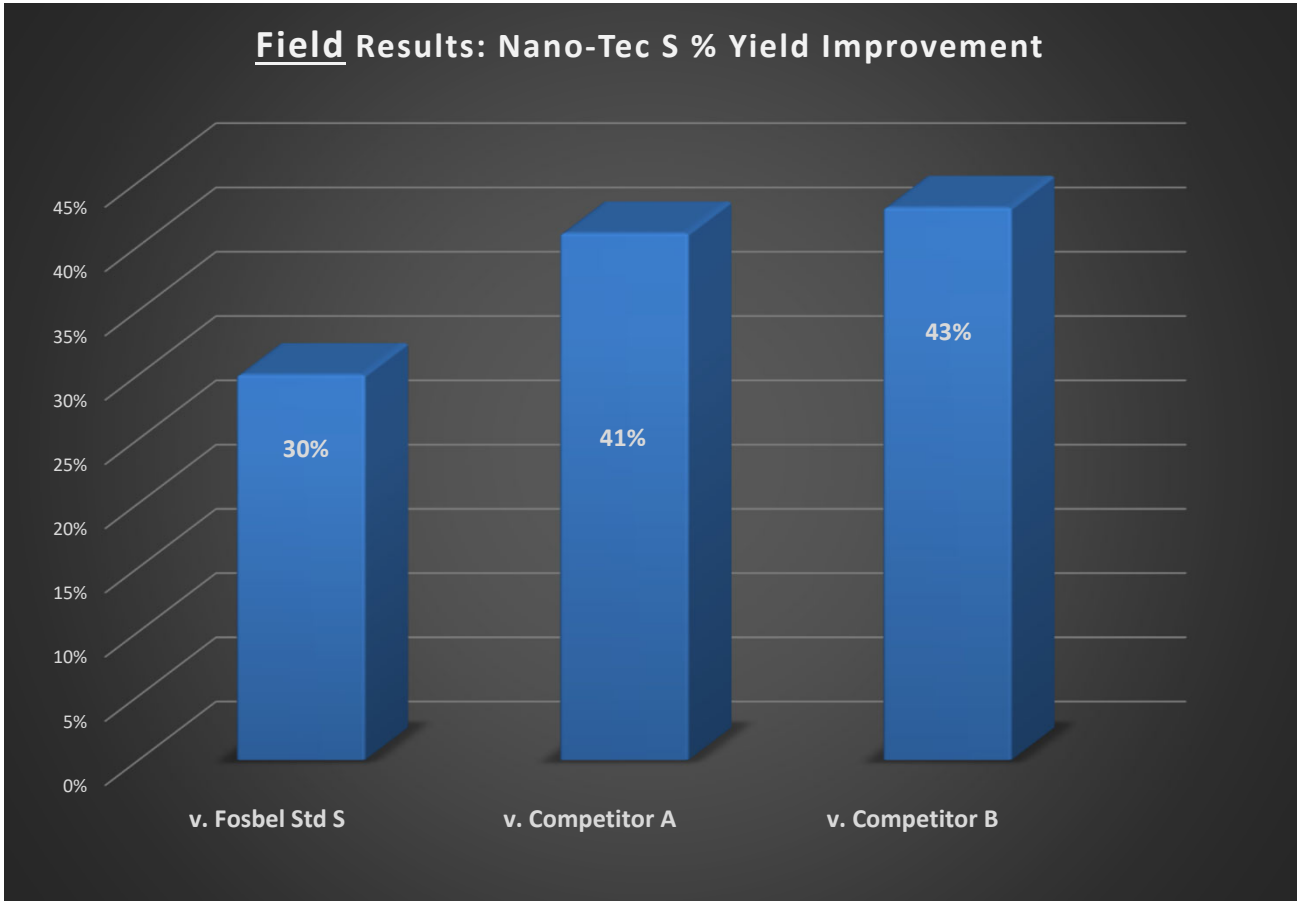
Lab Results for Nano-Tec™ S and Competitor Products (Coke)



Field Results for Nano-Tec™ S and Competitor Products (Coke)



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Innovation for the Glass Industry

Nano-Tec™ SG and Nano-Tec™ SGS

Fosbel Nano-Tec™ materials for the glass industry

- Silica (SG)
- Fused Silica (SGS)

Nano-Tec™ Benefits v. Standard Products

Improved Yield

- Lower rebound
- Higher yield
- Reduces contamination risk

Improved Physical/Chemical Properties

- Higher density
- Lower permeability
- Greater abrasion resistance

Improved Safety

- 9 time less inhalable and 4 times less respirable sized crystalline silica particles

Improved Service Life

- Physical/Chemical properties allow for performance improvements

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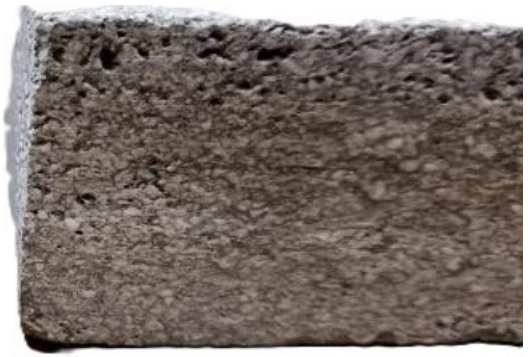
Lab Testing: Ceramic Welds



Open / Closed Weld Mass

Nano-Tec™ closed system weld mass

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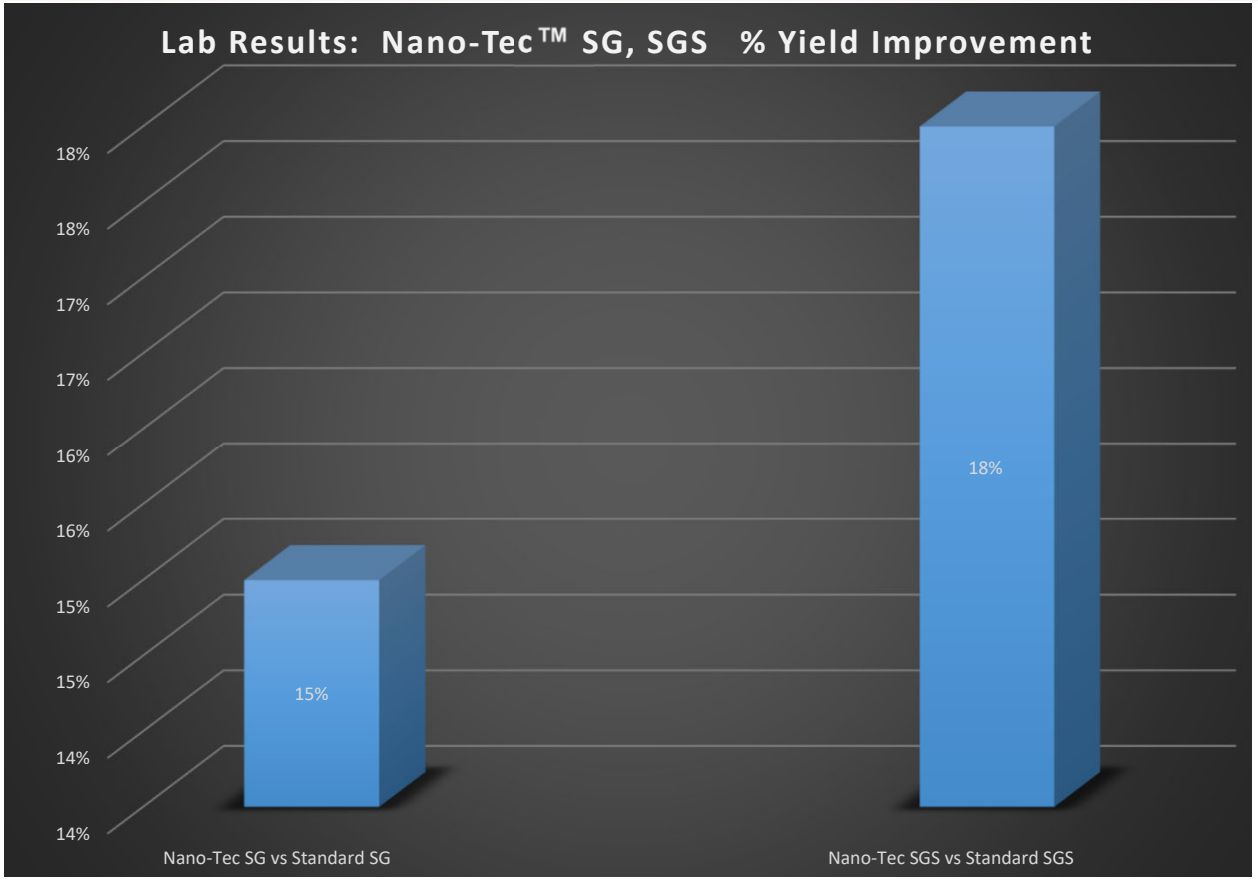
Yield Results for Nano-Tec™ Ceramic Welds

Results:

- **Nano-Tec™ SG/SGS exhibited 15-18% greater yield.**
- **Yield improvements reduced time on site 30%.**

Lab Yield Results for Nano-Tec™



Nano-Tec™ SG & SGS Conclusions

- **Service life objectives influence system (open vs closed)**
- **Nano-Tec™ materials offer service life and operational efficiencies**
  - Physical properties
  - Yield enhancement
- **Lab and beta site case study in Southeast Asia confirmed efficiencies**
  - 15%-18% lab
  - 30% time saving at site
- **Economics**
  - 30% time savings
    - Less ceramic welding material
    - Less labor to carry out SOW

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Innovation for the Glass Industry

Customer Controlled Field Trial

Fosbel SGS2 vs Nano-Tec™ SGS

Customer Controlled Field Trial

A customer conducted their own trial to compare the performance the Fosbel SGS2 material to the Fosbel Nano-Tec SGS material with respect to weld life and cost of application in an operational container glass tank.

Trial of Nano-Tec™ SGS

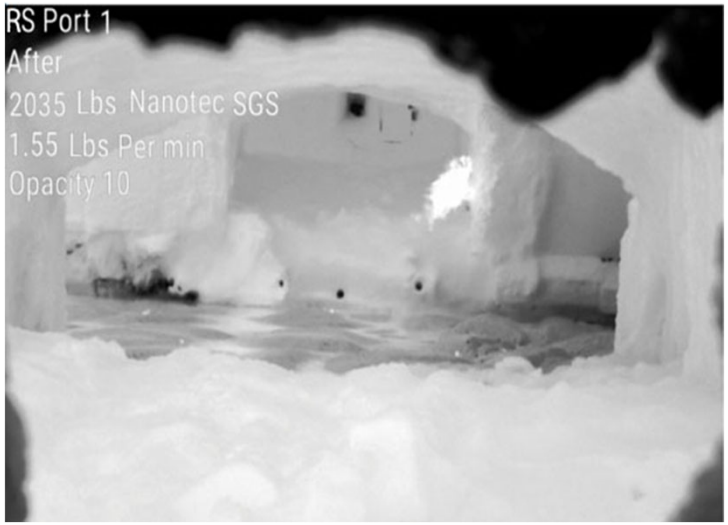
General Furnace Conditions

- Age: 9 Years
- Type: Conventional Cross-Fired w/ OEAS
- Fuel: Natural Gas
- Trial Repair Areas: Port 1 Right and Left

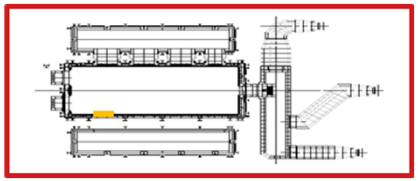
Right Side Port 1
Nano-Tec™ SGS April 1st 2020

Before

2,035 Lbs. Nano-Tec™ SGS
1.55 Lbs. Per Minute



After



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Right Side Port 1
Nano-Tec™ SGS

4 Months Service

11 Months Service

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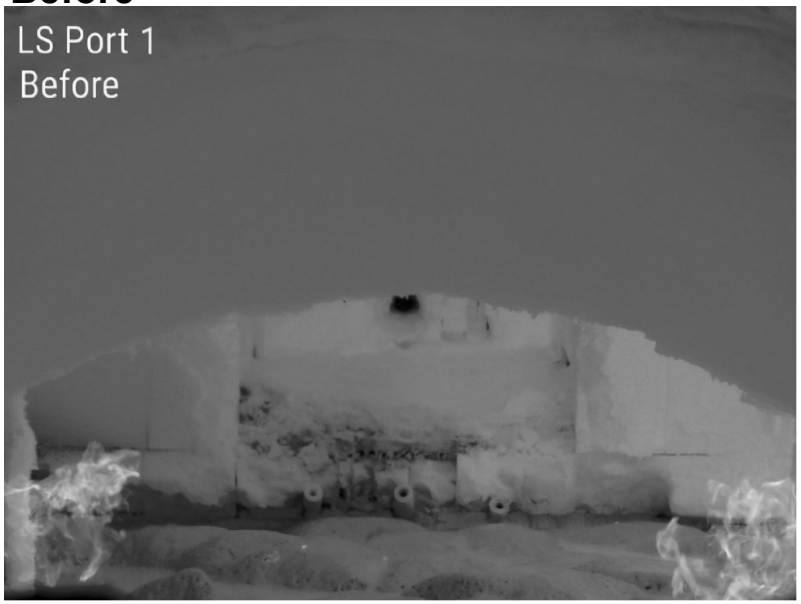
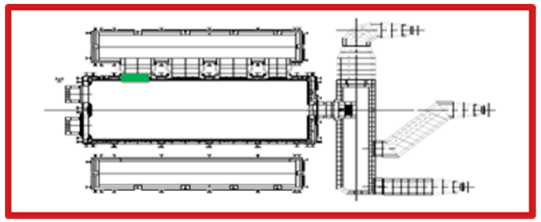
Left Side Port 1
April 1st 2020

Before



After



1,485 Lbs. SGS2

1.55 Lbs. Per Minute

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Left Side Port 1
SGS2

August 28,2020

4 Months Service

March 16, 2021, SGS2

11 Months Service

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Field Conclusions

- Standard SGS2 on LHS P#1 had worn off after almost one year in operation
- Nano-Tech™ SGS weld mass had partially worn away, but is still present.
- Nano-Tech™ SGS weld material remains after 11 months service

March 16, 2021, SGS2, P1 LHS – Worn off

March 16, 2021 NT SGS P1 RHS

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Nano-Tec™ Savings

Savings done Port 1 / RHS

Estimated: 30 hours / 2500 lbs. SGS2

Actual: 22 hours / 2035 lbs. Nano-Tec™ SGS

- Material: 26.6% directly saved
- Labor: 18.6% directly saved
- Longer repair life expectation (indirect savings)

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Conclusions

Utilizing Nano-Tec™ over SGS2 Material

- Less rebound resulting in…
  - Less risk of contamination / inclusions
  - Lower particulate / opacity during welding

- Longer repair life resulting in…
  - Significantly decreased hot repair spending
  - Less frequent ceramic welding repairs – less risk

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Ceramic Welding

Next Generation Welding Powder

Glass Contact AZS Weld

Project Omega – Field Trial, Metal Line

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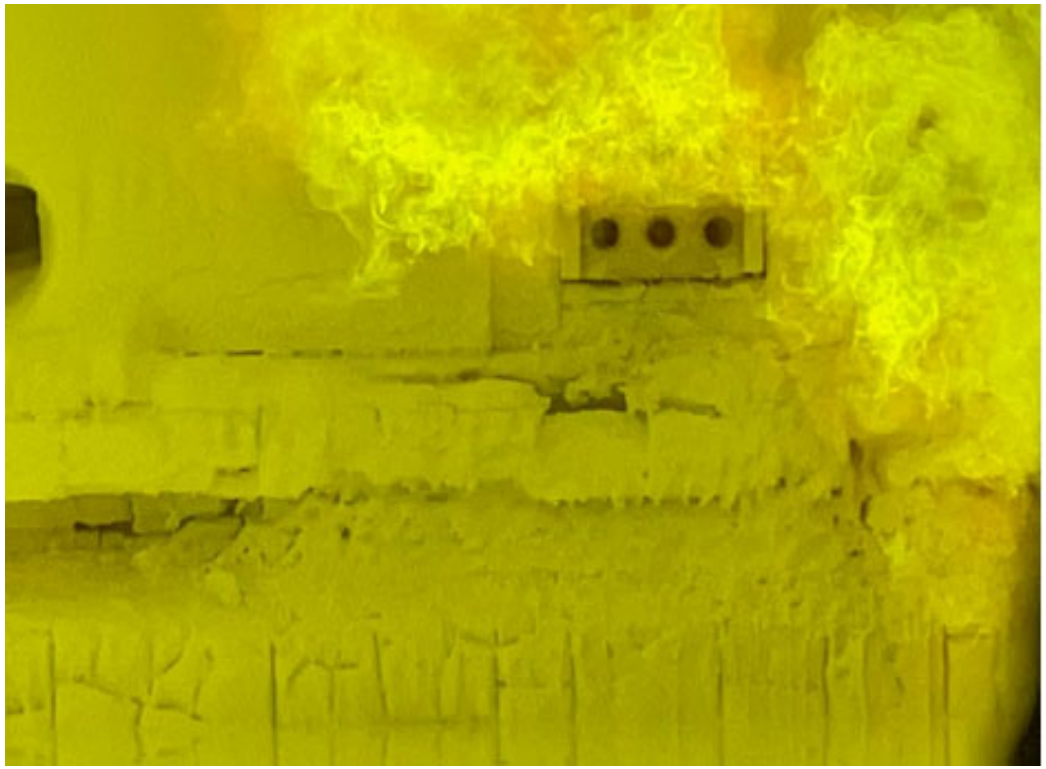

The Day of Weld Application

Project Omega – Field Trial, Metal Line (8 Months)

FB-71 Chemistry

Objective:

- Increase the zirconia content to improve glass resistance.

Omega Weld Chemistries

4-Dec-24	Sefpro CS-3	FB-69	FB-71
Al_2O_3	49	49.5	39.2
ZrO_2	34	33.4	39.4
SiO_2	15	15.7	17.7
MgO	-	-	1.6
Density (g/cc)	3.4	3.2	3.3
Porosity	<3	8.8	4.6