Application of Rapid Infrared Heating to Aluminum Forgings

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Outline

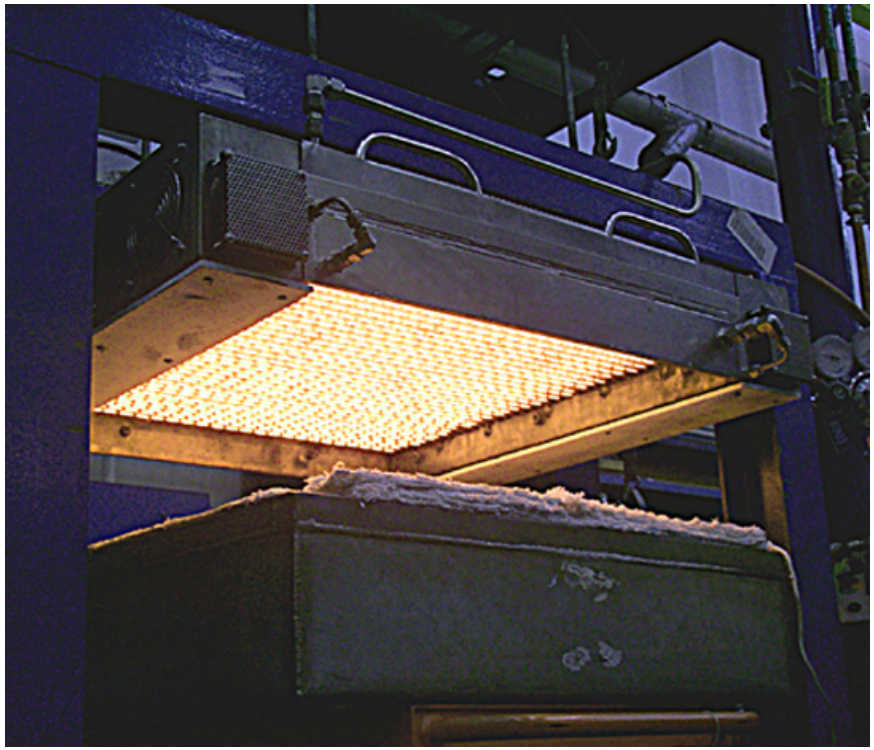
- Infrared Applications in Forgings
- Infrared Technology
- Field testing of a full-scale production setup at Queen City Forging
- Energy Savings and Other Benefits
- Improvement in metallurgical and mechanical properties
- Conclusions

Infrared Applications in Forging

Insert Die Heater

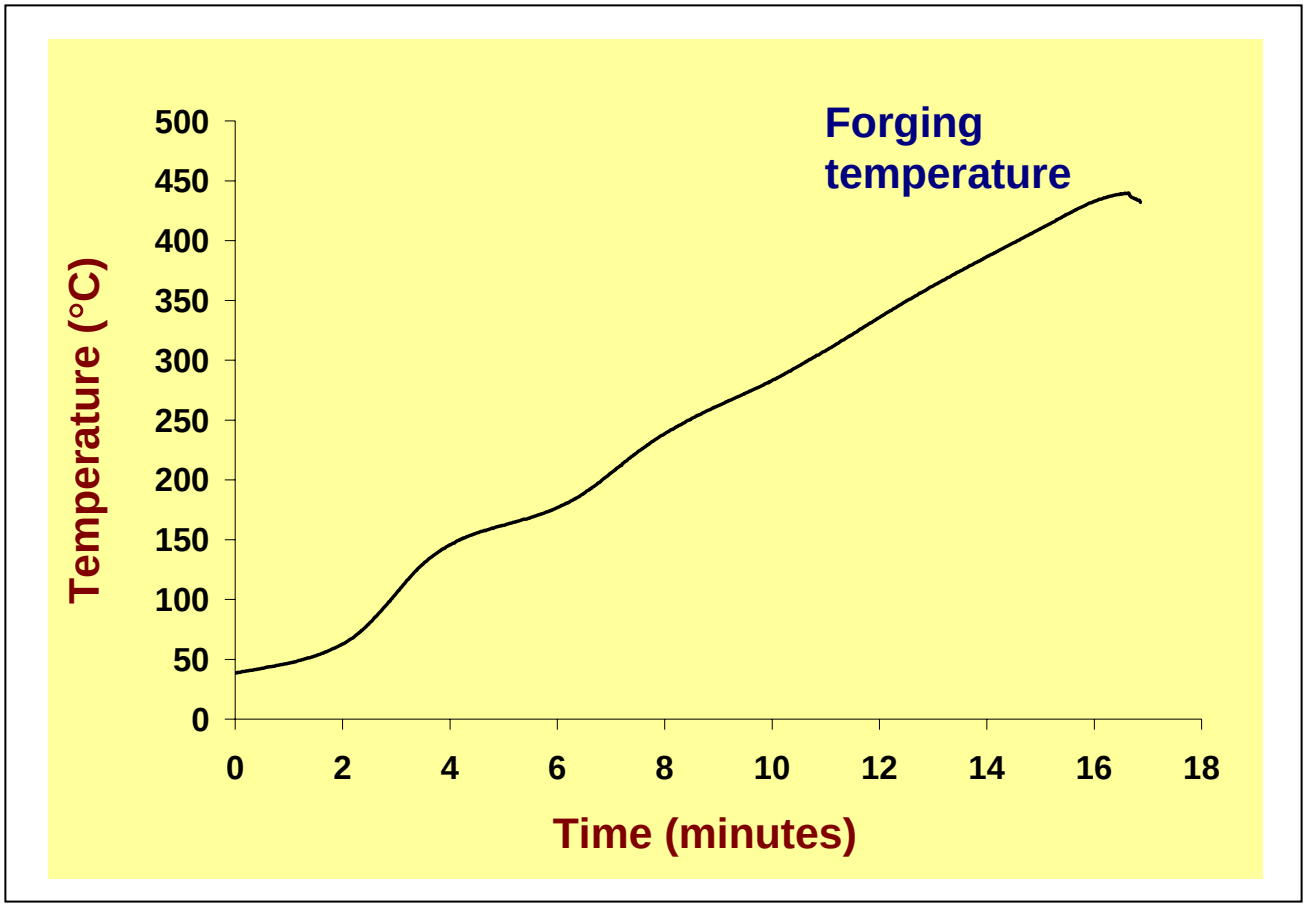
- Increase in Productivity
  - Reduced heating times
- Increase in die life
  - Uniform temperature
  - Better lubrication, lesser sticking problems
- Energy savings
  - Efficient heating and shorter wait times in between forging

Infrared Applications in Forging



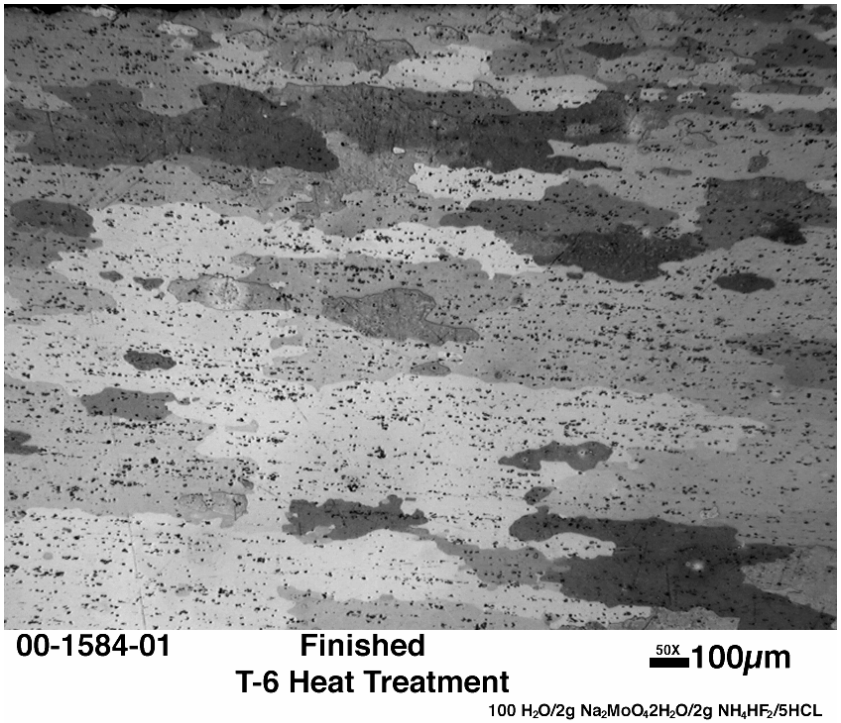
Laboratory based batch-type infrared furnace used for aluminum billet preheating prior to forging

Infrared Applications in Forging



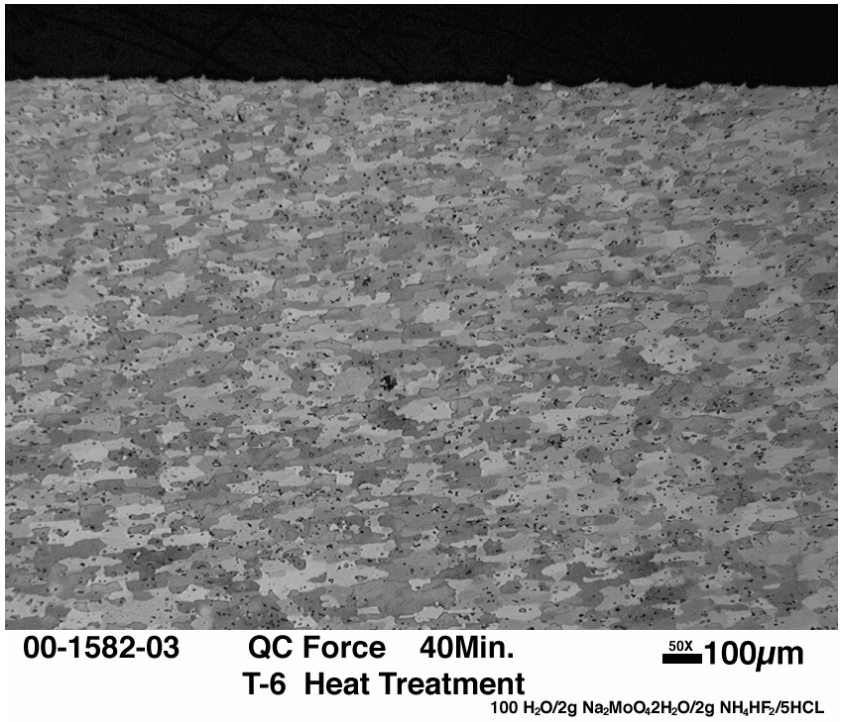
2.25 inch-diameter, 6-inch-long AA 2618 billets were heated in 16 mins (Conventional convection furnace takes atleast 1.5-2 hrs)

Infrared Applications in Forging



Convection Heated/Forged and T-6 Heat Treated (AA 2014)

(Grain size = 170 μm)



Infrared Heated/Forged and T-6 Heat Treated (AA 2014)

(Grain size = 59 μm)

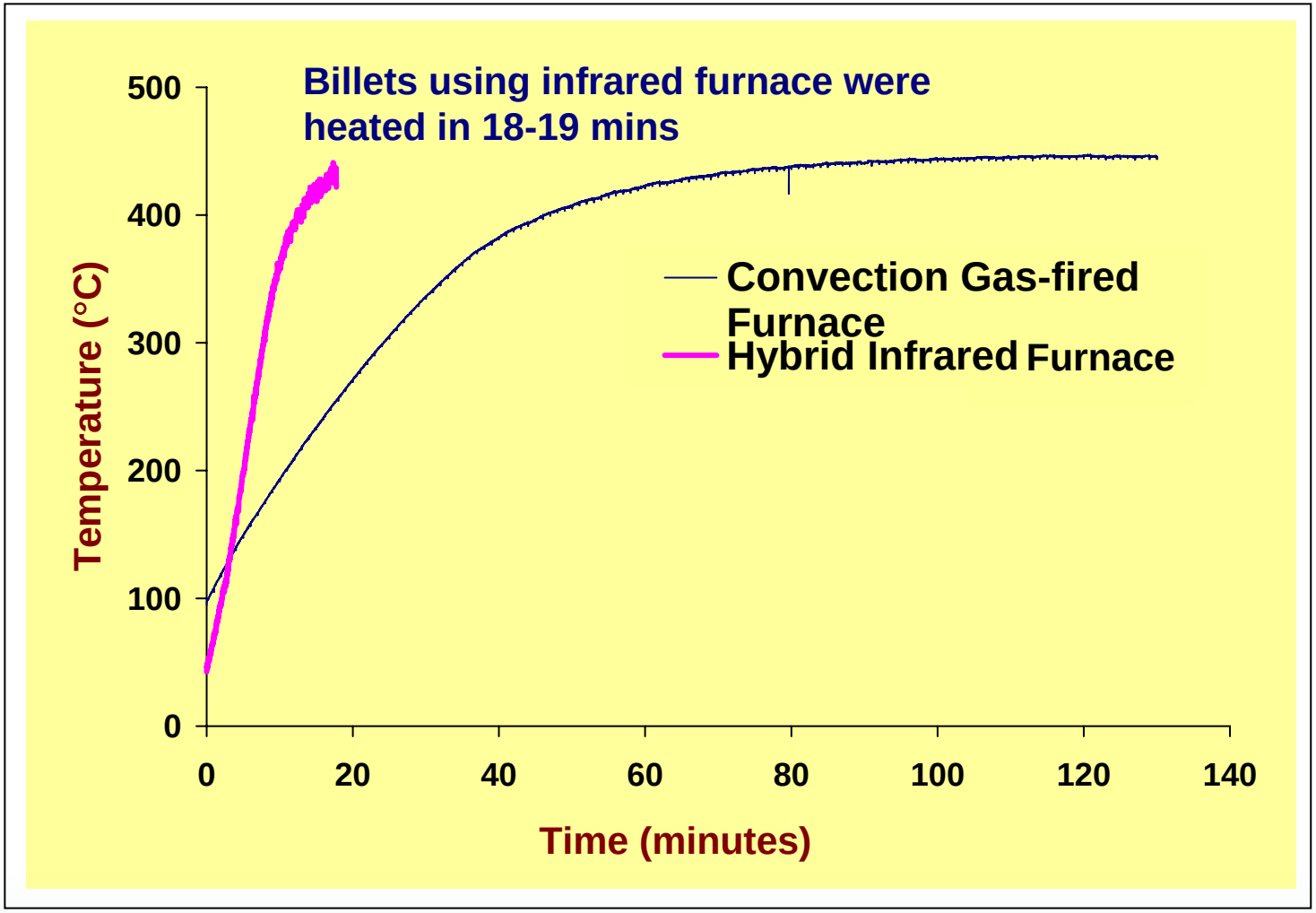
Infrared Technology

- The tungsten halogen heating element is heated in excess of 4000˚F which increases thermal transfer
- Radiated energy heat flux is nearly ten times of a gas-fired infrared system.
- Covert electrical into radiant energy in excess of 90%.
- The filaments go from cold to full power in less than one second and shut down in one second.
- Uniform deposition of radiant energy.

Full-scale production setup

- Hybrid infrared furnace setup at Queen City Forging
- Optimized combination of radiant and convective heating
- Continuous belt setup for higher throughputs

Full-scale production setup



Heating of 2.25 inch-diameter, 6-inch-long AA 2618 billets

Energy Savings and Other Benefits

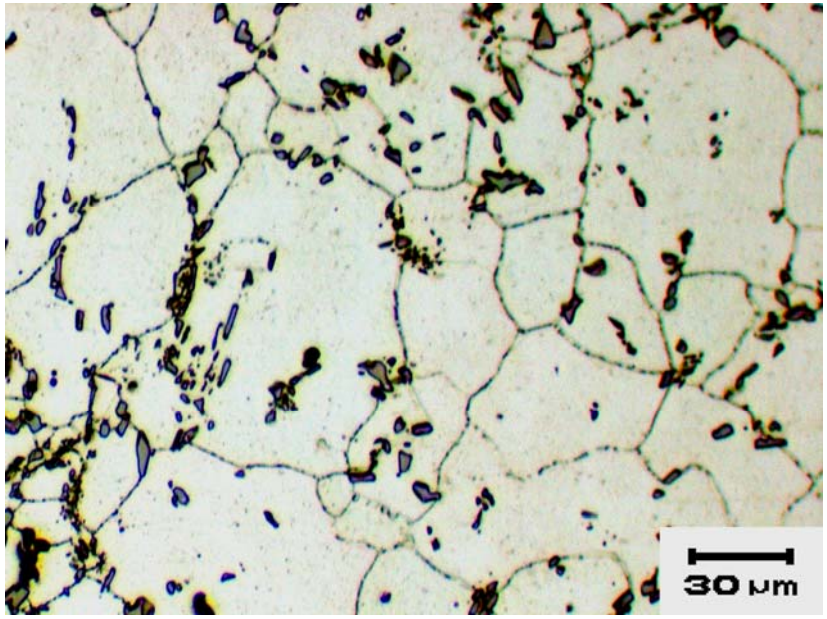
- Reduced heating times and increased productivity
  - Conversion efficiencies of 90%
  - Optimized combination of radiant and convective heating
  - High heat transfer rates

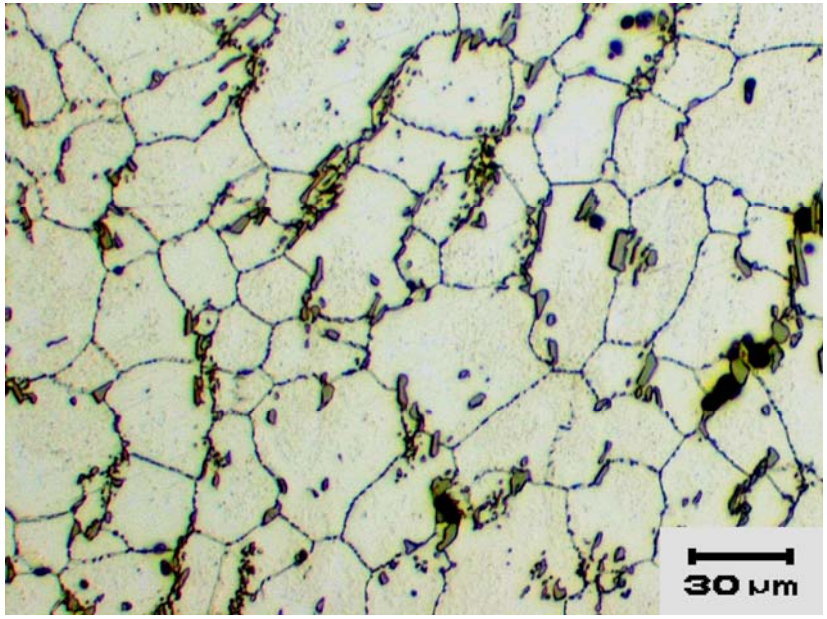
- Energy Consumption
  - Conventional gas-fired convection furnace takes approximately 1200,000 BTUs to heat a 500 lb load of billet to temperature in a 5-6 hour period
  - Hybrid infrared system would take 200,000 BTUs to heat the same load in almost one hour with a continuous belt type setup

Energy Savings and Other Benefits

Attribute	Continuous-belt Hybrid Rapid Infrared Furnace	Batch-type Conventional Convective Gas Fired Furnace	Comments
Billet heating time (mins)	20	240	Infrared heating provides an order of magnitude faster heating
Throughput (Production rate) (lbs/hr)	350	80	Rapid heating using infrared increases the production rates 4 times
Energy used for Al billet heating (BTU/lb)	500	1500	Energy consumption using infrared system is reduced by a factor of three
Overall efficiency of the system (%)	~ 30	~10	Infrared systems are three times more efficient than convection gas-fired furnaces

Improvement in Metallurgical Properties



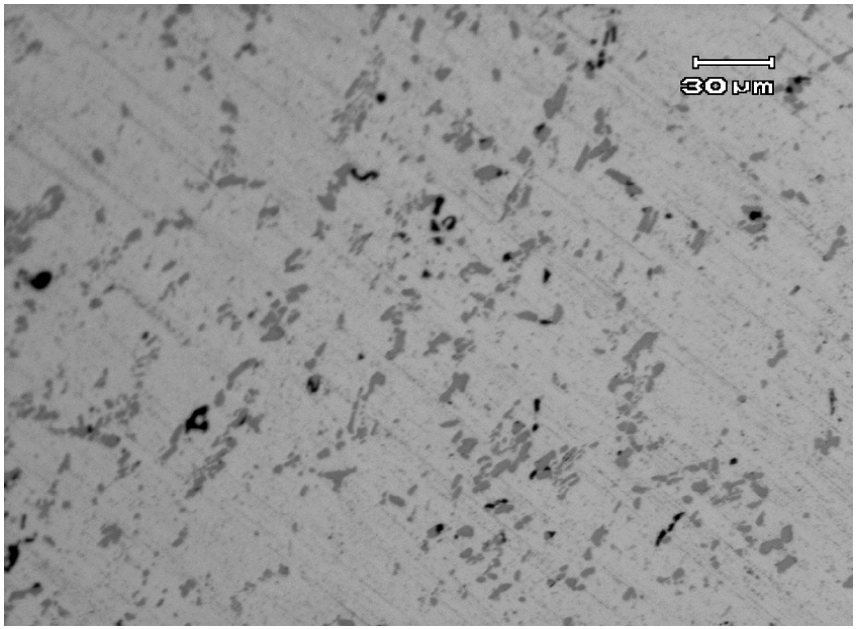


Conventionally preheated, forged, conventionally solution heat-treated and conventionally aged (*Controlled)

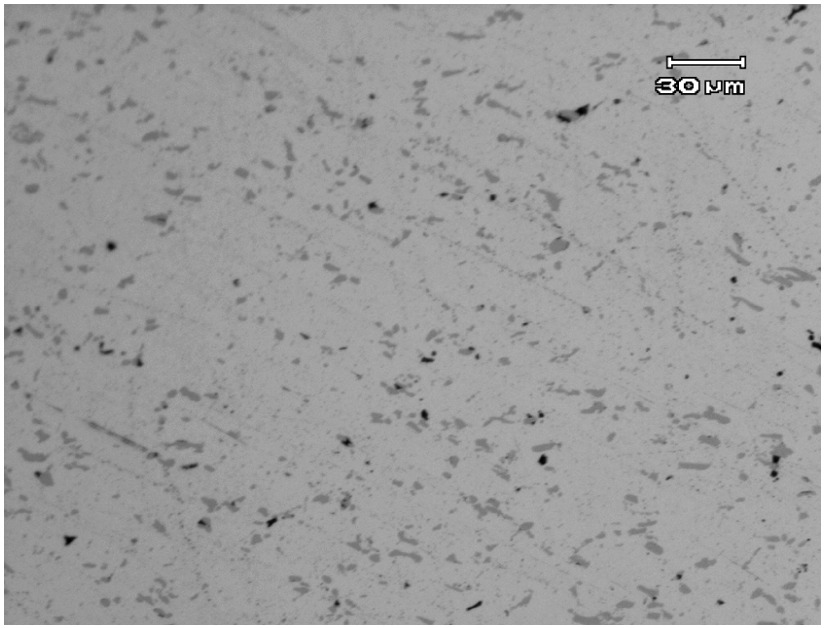
Rapidly preheated, forged, rapidly solution heat- treated and conventionally aged

30% Reduction in grain size with rapid preheating and rapid heat-treatment

Improvement in Metallurgical properties



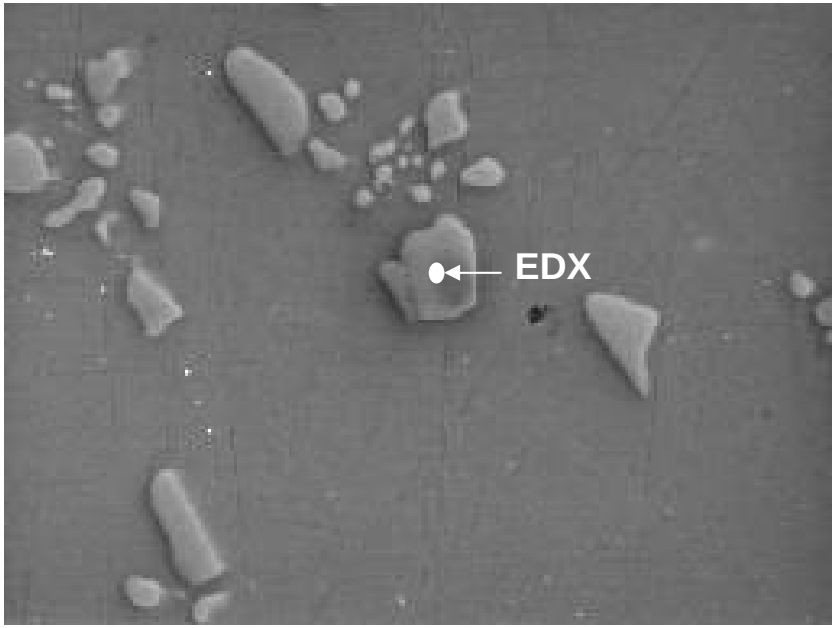
Rapidly heated, forged and air-cooled

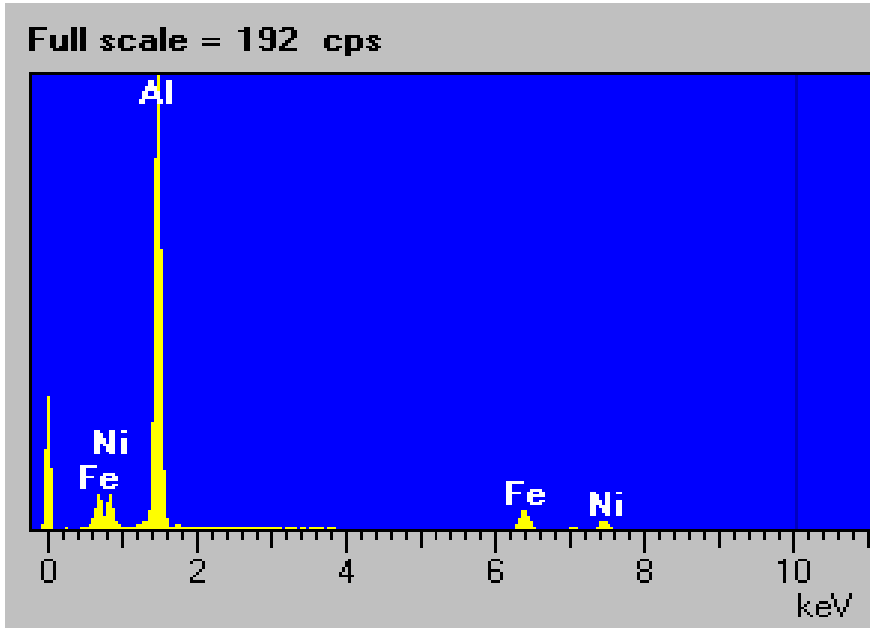


Conventionally heated, forged and air-cooled

- Grain refinement resulted from the grain boundary pinning effect of the intermetallic particles

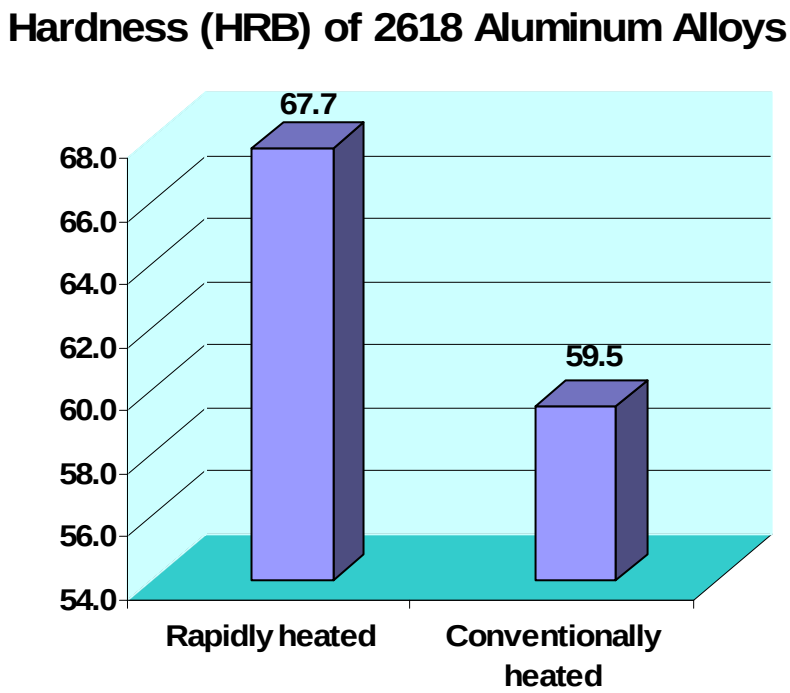
Improvement in metallurgical properties

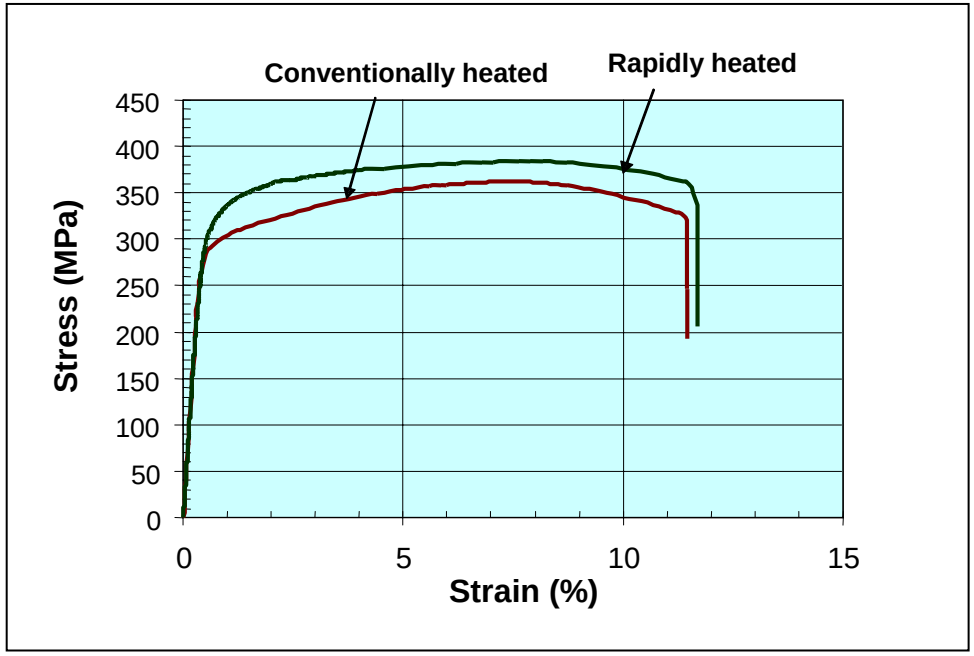




- Intermetallic particles pinning at grain boundaries are Al_9NiFe confirmed by EDS

Improvement in mechanical properties





- Higher hardness and UTS values were achieved with rapidly heated forgings
- Improved strength is due to stronger age hardening and not grain refinement

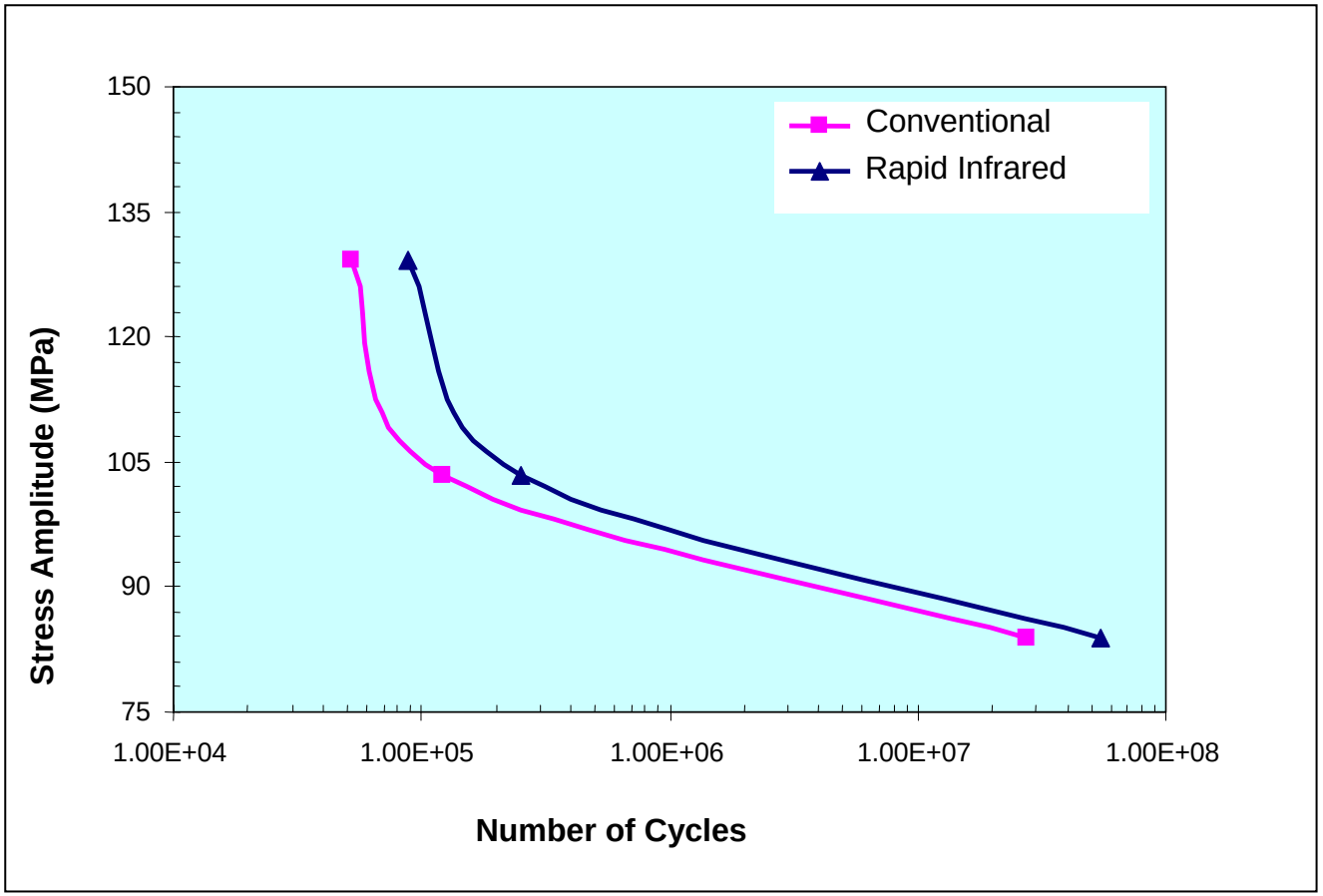
Improvement in mechanical properties

Chemical Composition of Aluminum 2618 alloy

Wt%	Si	Fe	Cu	Mg	Ni	Zn	Ti	Al
Min	0.1	0.9	1.9	1.3	0.9	0.1	0.04	Rem
Max	0.25	1.3	2.7	1.8	1.2		0.1	

- Age hardening effect in AA 2618 is due to fine and homogeneous distribution of Cu-rich strengthening phases such as GP zones and S' ($CuMgAl_2$)
- Longer soaking times at solutionizing temperature could result in depletion of Cu in α-Al matrix
- Cu may form other stable compounds with iron and nickel, $(CuFe)Al_3$ and AlCuNi

Improvement in mechanical properties



- Grain refinement improves fatigue life

Conclusion

- Rapid infrared heating offers a low cost, energy-efficient heating methodology for preheating aluminum billets
- Field testing of this hybrid infrared system in full-scale production setup has demonstrated cost savings up to 40-50% through reduced energy consumption, increased throughput and improved consistency in the process and quality of the product.
- Rapidly preheating and rapidly solution heat-treating produces stronger forgings with two times the fatigue life
- Close control of temperature and output and reproducible and consistent heating allows automation of the process
- Reduced rejection, scrap, rework and labor costs
- Potential national energy savings of 2.21×10^{10} BTUs/year together with cost savings of 130 million dollars/year.

Other potential applications

- Solution heat treatment of aluminum forgings
  - A 10-h solutionizing cycle could be reduced to 1.5 h, consuming only 20% of the energy currently used by conventional techniques
- Other thermal processes
  - Stress relieving, Annealing and Artificial Aging
  - Preheating and post-weld annealing in joining
  - Preheating prior to extrusion, rolling, and similar hot-working processes.
- Other Materials
  - Steel, brasses and bronzes, titanium alloys, and nickel and cobalt-based alloys

Full-scale production setup