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IAGT Industrial Application of Gas Turbines

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Practical Experience With Full Solution Rejuvenation of Single Crystal Gas Turbine Blades

By

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LIBURDI TURBINE™

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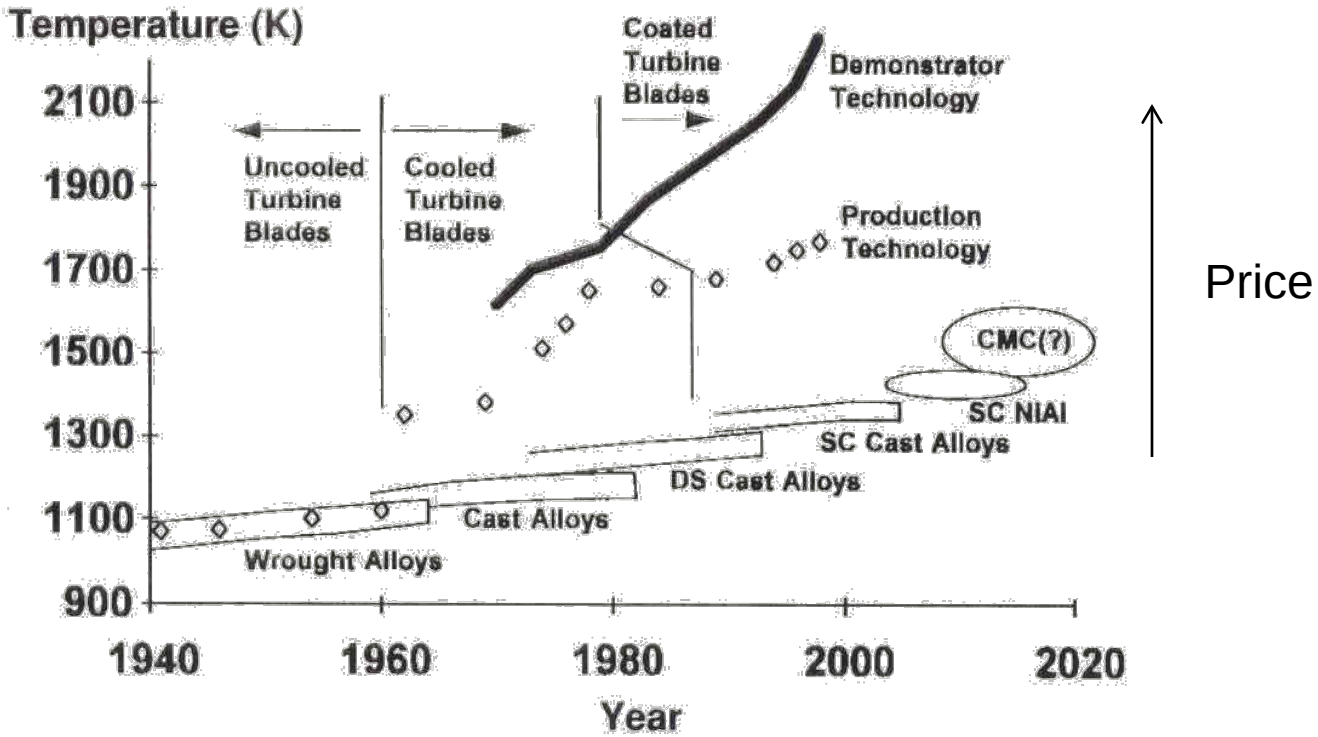
Introduction



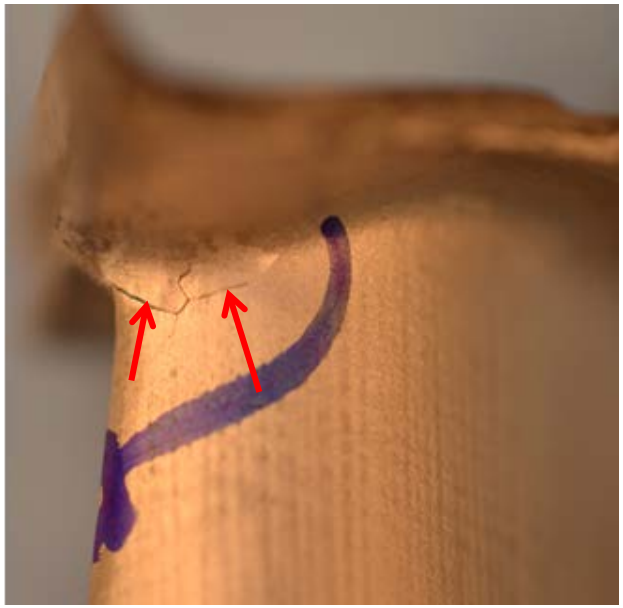
- Improved capability, increased cost of components
- Further incentive for operators to maximize life of components

Introduction

- In many cases OEM life of industrial single crystal (SX) blades = 2 service intervals of 18k – 25k hours with one mid-life strip and recoat repair
- Limits appear to be conservative based on destructive examination of 'life expired' SX blades
- >30 years experience extending the life of equiaxed and DS alloys through full solution rejuvenation heat treatment
- The primary concern with full solution rejuvenation of SX alloys is the formation of recrystallized (Rx) grains on surfaces with residual stress (low levels of grain boundary strengthening elements)

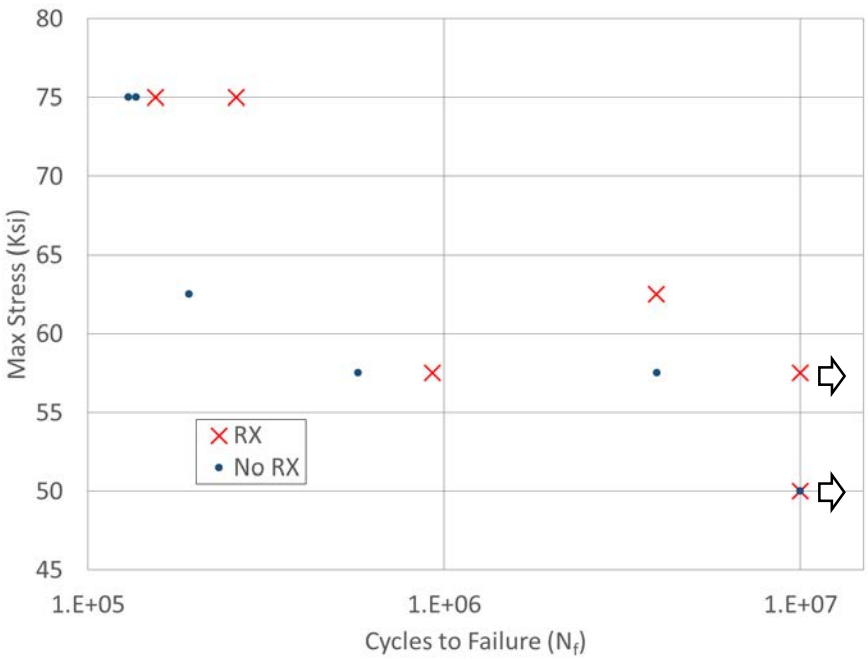
Introduction

- Recrystallization: the formation of a new grain structure in a deformed material by the formation and migration of high angle grain boundaries driven by the stored energy of deformation.
- Recrystallization (Rx) results in reduced high temp fatigue life and stress rupture strength at temperatures ≥850°C (1560°F) of SX alloys
- Previous study: recrystallization not practically avoidable on previously peened surfaces when subject to above the γ' solvus solution HT



Introduction

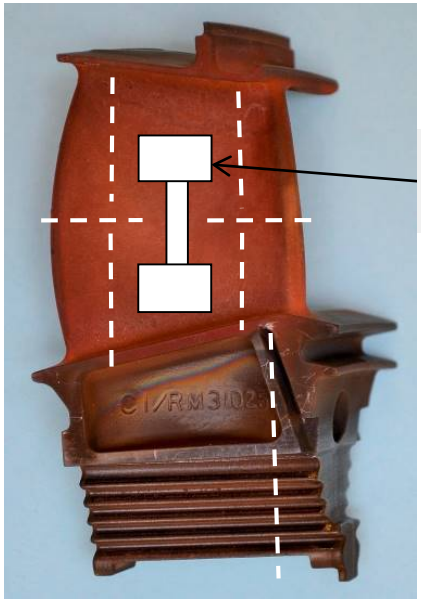
- Previous study found that recrystallization did not result in a reduction in high cycle fatigue life of René N5 SX alloy tested at 650°C
- Indicates rejuvenation HT of previously peened SX blades is feasible provided that Rx be limited to root surfaces which operate at or below 650°C
- Next step: demonstrate feasibility on representative parts



Scope of Analysis

- Life expired SGT-100 HPT blades, CMSX-4 alloy
- 28,000hrs → repair → 12,000hrs → life expired per OEM limit
- 1 blade examined in service run, as received condition
- Trial repair on 5 blades including: removal of the coating, dimensional and penetrant inspection, rejuvenation heat treatment, Rx grain inspection, platinum aluminide coating.

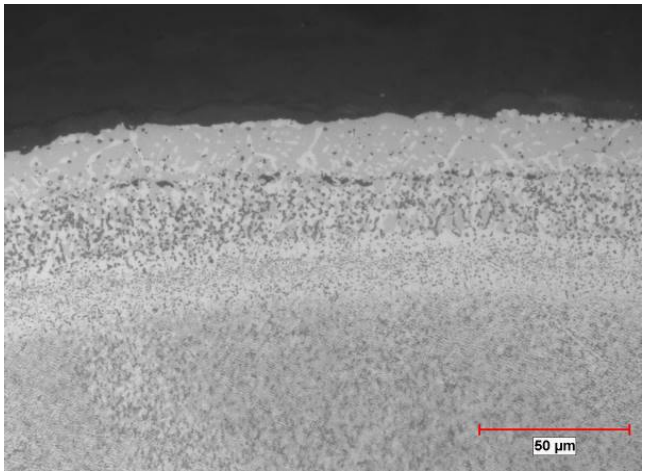
SGT-100 HPT Blades

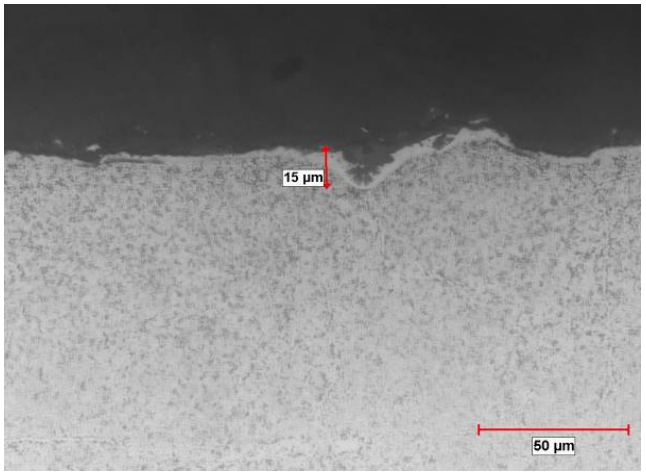


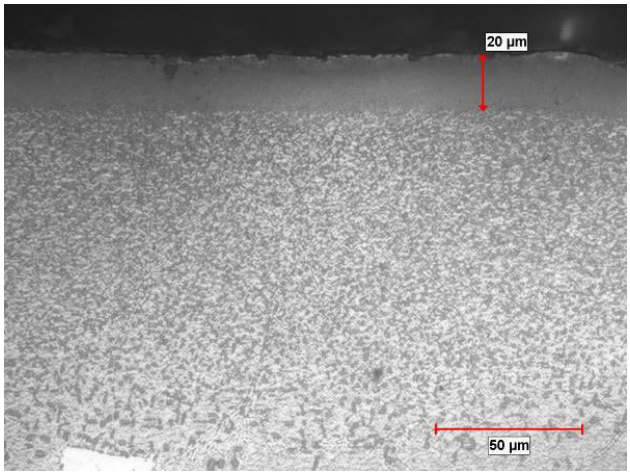
Sectioning plan

As Received Condition

Surface Condition







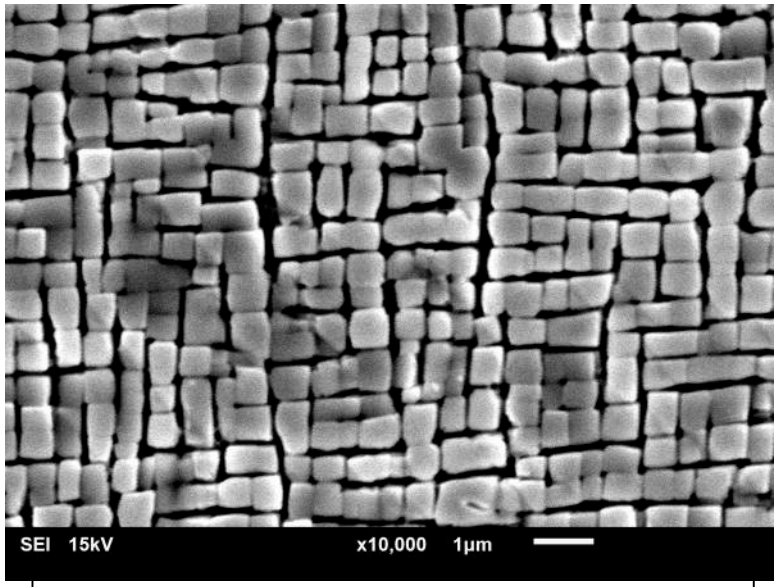
External airfoils surfaces platinum aluminide coated. Coating partially consumed, no base alloy damage.

Internal airfoil surfaces uncoated. Minor base alloy oxidation <25µm (0.001 inches) deep.

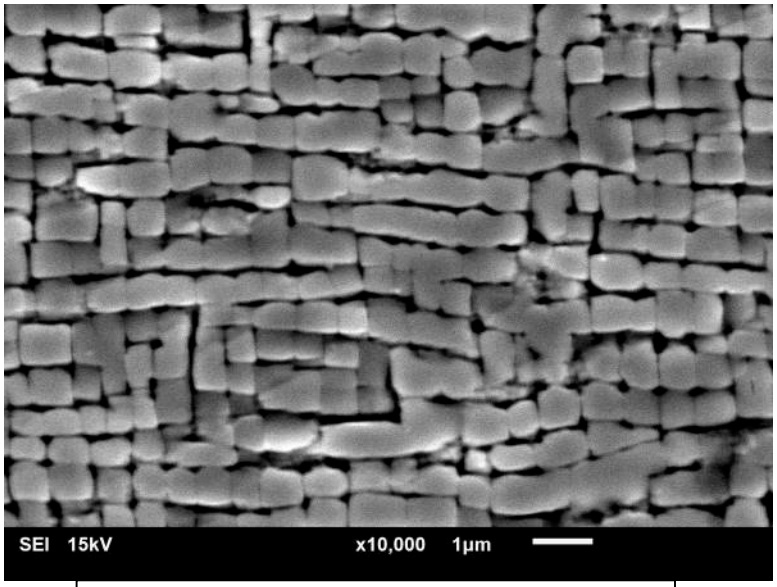
Root surfaces exhibited 20µm thick alloy denuded layer. No Rx on root surfaces.

As Received Condition

Base Alloy Condition



Root (pre service condition)



Mid airfoil trailing edge

As Received Stress Rupture Test Result (997°C, 250 MPa)

Location	Life (hours)	Elongation (%)
Mid chord airfoil	82.8	30.6

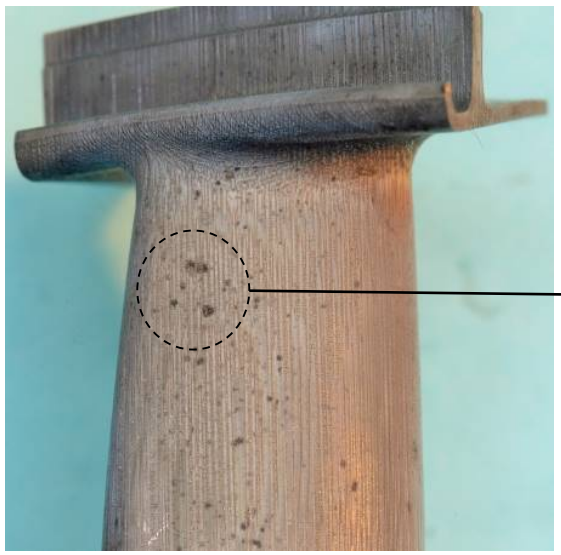
Repair Trials
Non-destructive inspection

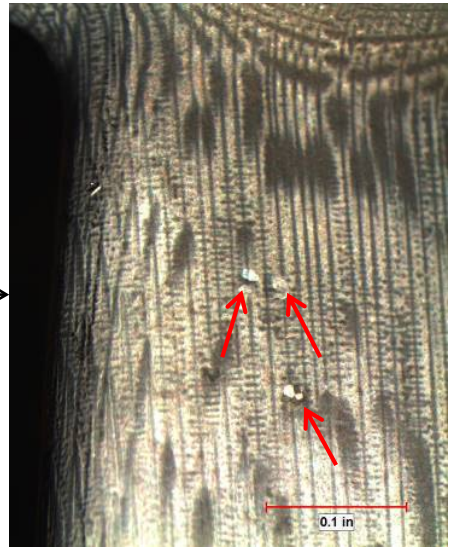
- No cracks or defects by FPI
- Dimensional inspection on 3 blade audit for: TE thickness, root width, wall thickness, and seal height
  - All met acceptance criteria

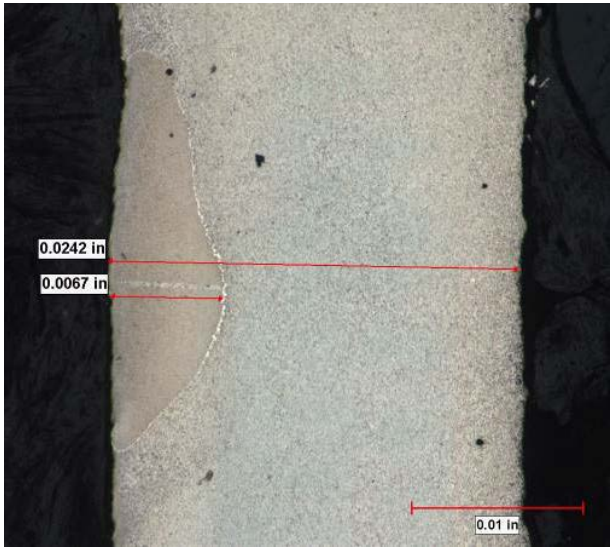
Typical pre and post heat treatment CMM deviation analysis showing no significant dimensional change

Repair Trials
Surface Condition

- After rejuvenation processing, the blades were inspected for recrystallized grains in critical areas by chemical etching
- 4 out of 5 blades were found to exhibit recrystallized grains in critical areas to varying extents
- Destructive examination verified that the depth of Rx in the case of at least one blade was beyond serviceable limits



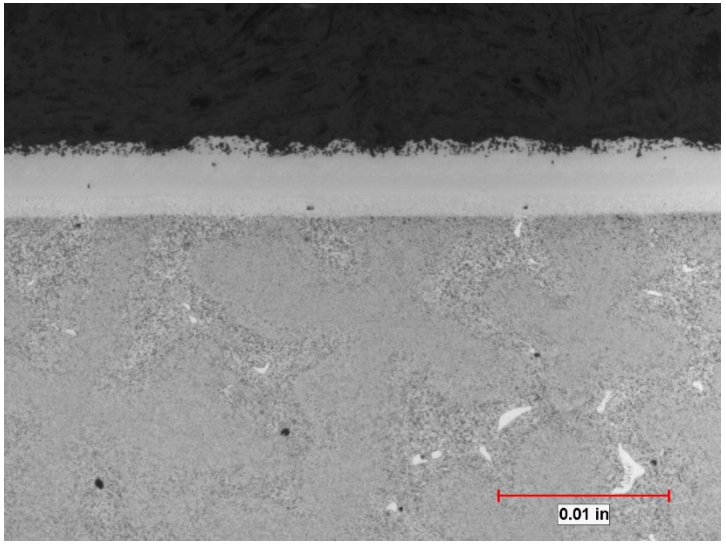


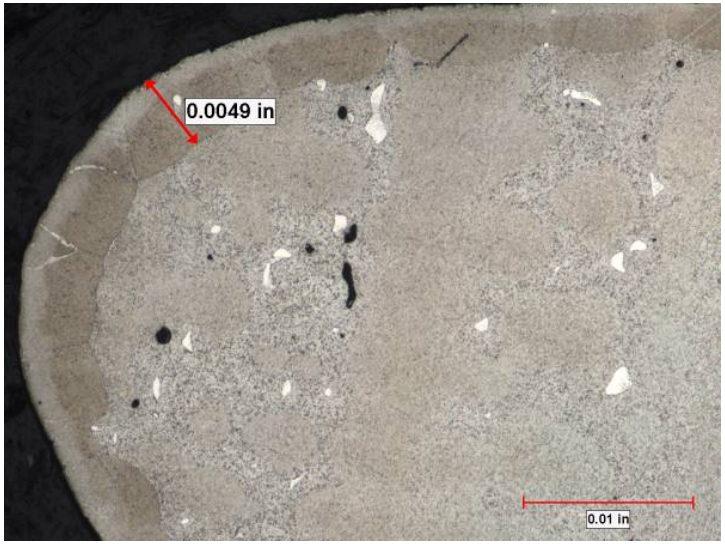


Repair Trials
Surface Condition II

- Based on finding, additional 12 blades analyzed – 7 from same blade set as the original group, 5 from a different blade set.
- All blades: coating removal and rejuvenation processing followed by macro etch inspection for recrystallized grains
- All blades were found to initially exhibit some recrystallized grains in critical areas to varying extents
- Put through a cycle of mechanically removing the grains and re-inspection until the recrystallized grains had been eliminated from all critical areas
- 8 blades destructively examined to verify inspection results and assess remaining wall thickness
- All 7 blades from the 1st group and 4 out 5 blades from the 2nd group were found to be within repair limits.

Repair Trials
Surface Condition III



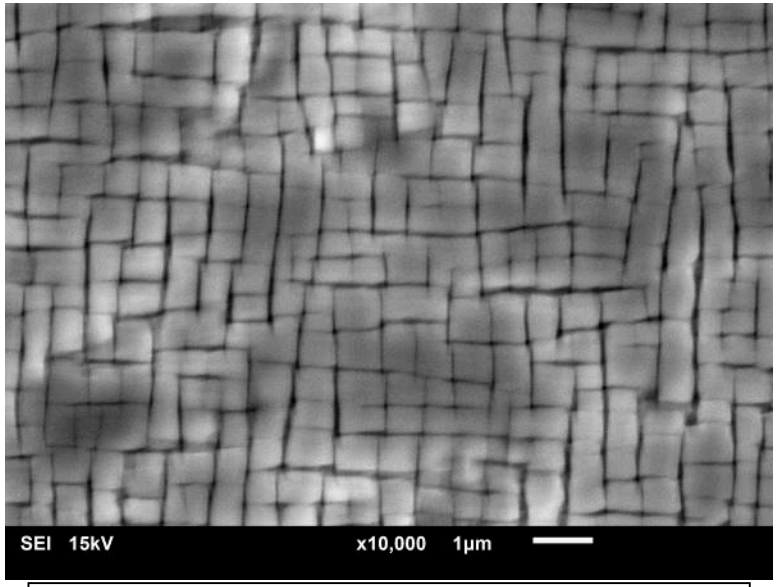


External airfoils surfaces all surfaces were found to be fully coated with platinum aluminide to specification.

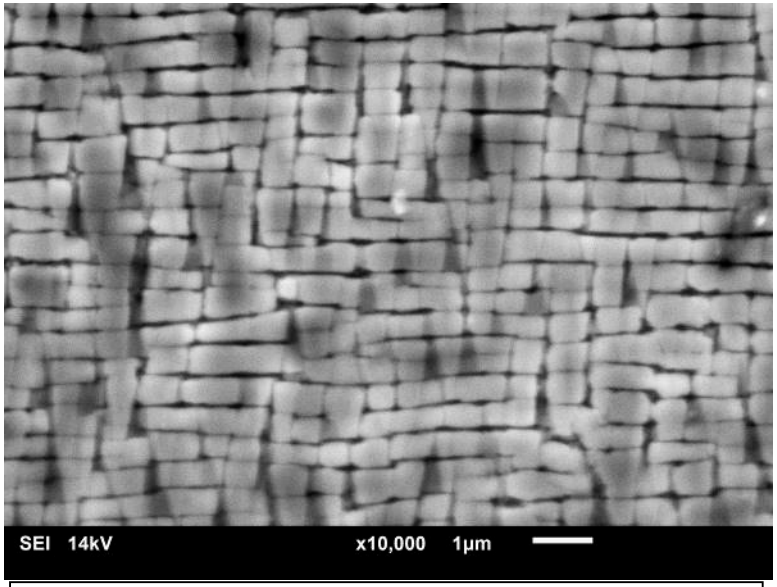
Root surfaces had uniform layer of recrystallized grains up to ~125µm (0.005 inches) deep.

- No Rx was observed on the internal airfoil surfaces of any of the examined sections.

Repair Trials
Base Alloy Condition



Root – post rejuvenation HT

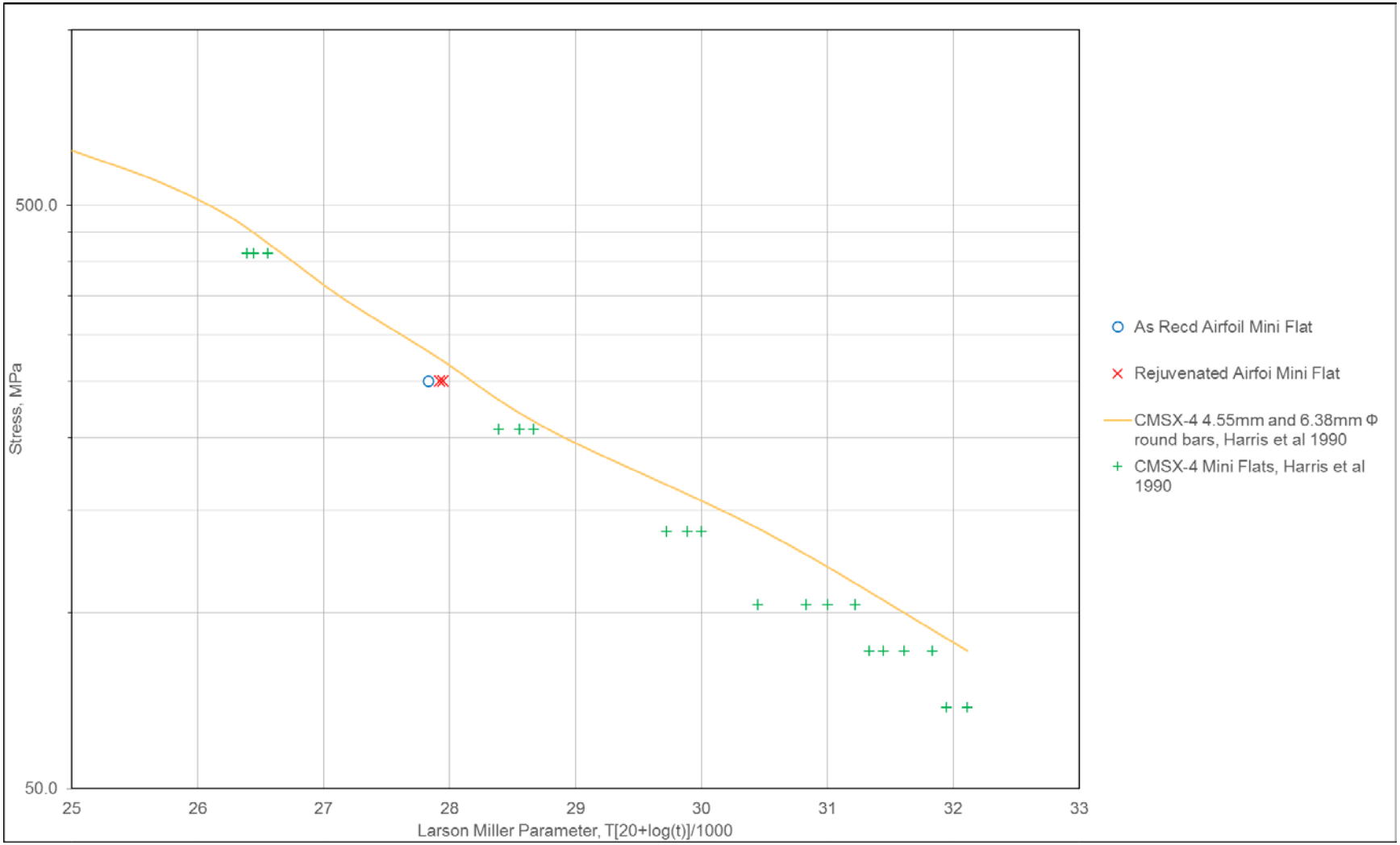


Mid airfoil trailing edge – post rejuvenation HT

Post Rejuvenation Stress Rupture Test Result (997°C, 250 MPa)

Blade	Location	Life (hours)	Elongation (%)
1	Mid chord airfoil	102.2	37.1
2	Mid chord airfoil	96.9	28.0

Repair Trials
Stress Rupture Testing



Discussion

- The examined blades were found to be in a serviceable condition despite having reached the OEM life limit.
- In cases where the life limiting damage mechanism is unknown, it is prudent to apply full solution rejuvenation heat treatment in order to anneal any pre-crack damage that may be undetectable by conventional testing.
- There may also be degradation of mechanical properties in locations of the blade where it is not possible to perform mechanical testing ex. in a shroud radius or thin trailing edge wall.

Discussion II

- The heat treatment applied resulted in a comparable microstructure to the as manufactured, with stress rupture properties equivalent to those published for fully heat treated CMSX-4 alloy.
- Full solution rejuvenation repaired blades need to be inspected for recrystallization – same as new single crystal casting → neither process expected to yield 100%.
- Demonstrated that a significant proportion of the tested blades were recovered within repair limits
- Rx identified on roots indicates surfaces peened at original manufacture/repair. Depth of Rx comparable to that tested in previous study.

Summary

- Full solution rejuvenation repair of single crystal blades is feasible (not currently practised within the industry)
  - Extend the life of expensive components
- The propensity for recrystallization depended on prior plastic deformation from manufacture, service, and/or repair processing
- An effective non-destructive inspection technique for recrystallized grains is necessary when performing this type of repair
- While some fallout is likely to occur, high repair yields can be achieved for this type of repair