Central Iron & Steel Research Institute

Microstructure Development of Cast TiAl for Industrial Turbine Blades

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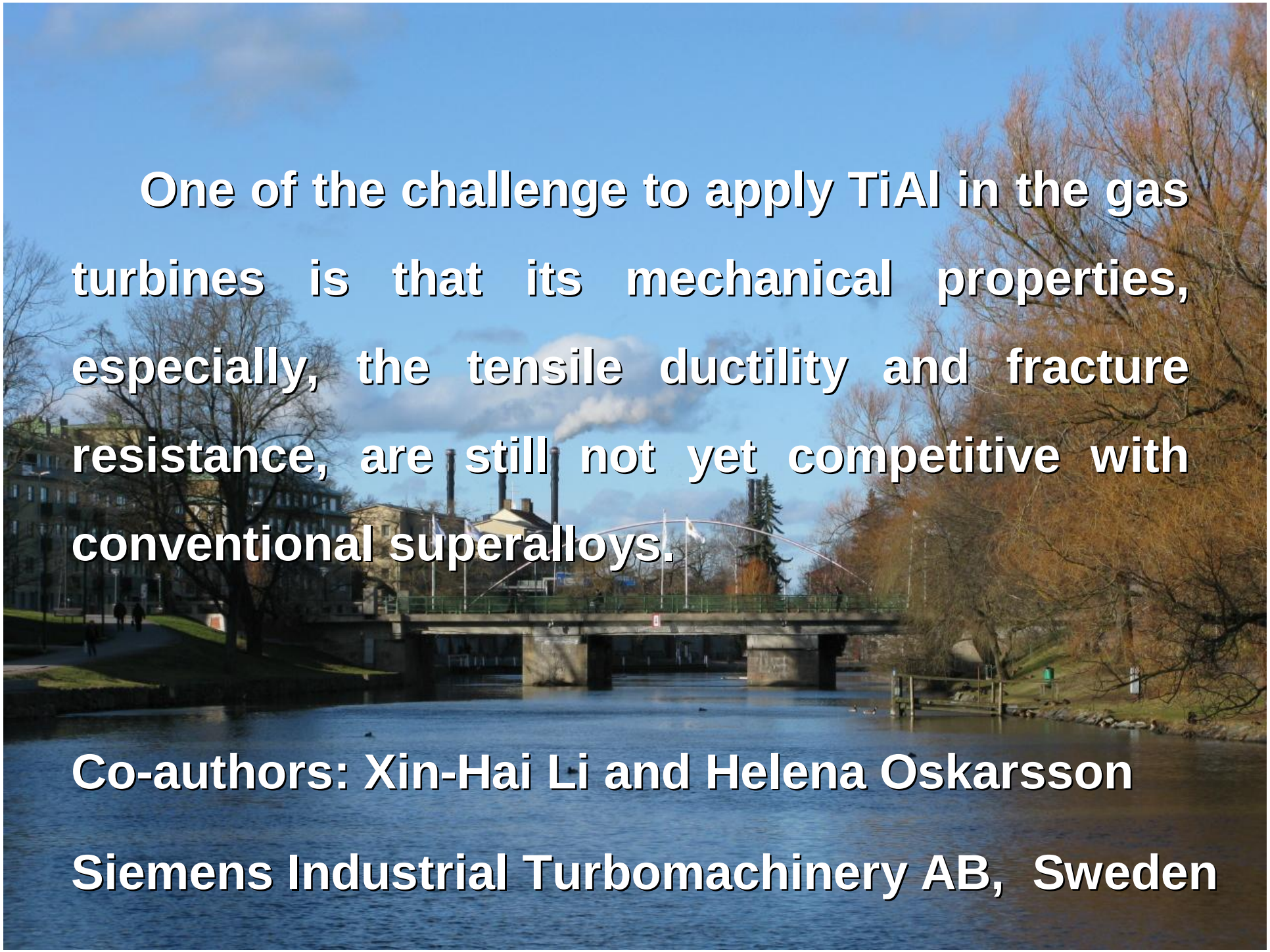
Background

Application of compressor / LPT blades in air engine and automobile turbochargers have clearly shown the advantages of use of light-weight TiAl rather than Ni-based superalloys.

TiAl gas turbines blades are prospected to be the next potential market for increasing both competitive power and environment friendship of this growing industry.



One of the challenge to apply TiAl in the gas turbines is that its mechanical properties, especially, the tensile ductility and fracture resistance, are still not yet competitive with conventional superalloys.

Co-authors: Xin-Hai Li and Helena Oskarsson

Siemens Industrial Turbomachinery AB, Sweden

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Background

Alloy System in CISRI

- The alloys system – TAC2 is based on the patent composition: Ti-47.5Al-2.5V-1.0Cr (at.%).
- Ti/Al atomic ratio is kept near to that of Ti-48Al and V and Cr additions are for increasing tensile ductility and impact resistance.

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Background

Facilities and Technology

3 – 10Kg Cold crucible vacuum induction levitation hearth

Centrifugal casting rotor for current turbochargers

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Outlines

- Approaches to improve the ductilty
- Development of desired microstructure
- Mechanical evaluation and discussion

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Approaches to improve the ductilty

Refine the Cast Microstructure

- Transform duplex microstructure by annealing
  - Produce finer lamellar colonies and γ grains upon degradation
- Get finer lamellar microstructure by multi-step HT
  - Get near gamma first then regain lamellar colonies from it

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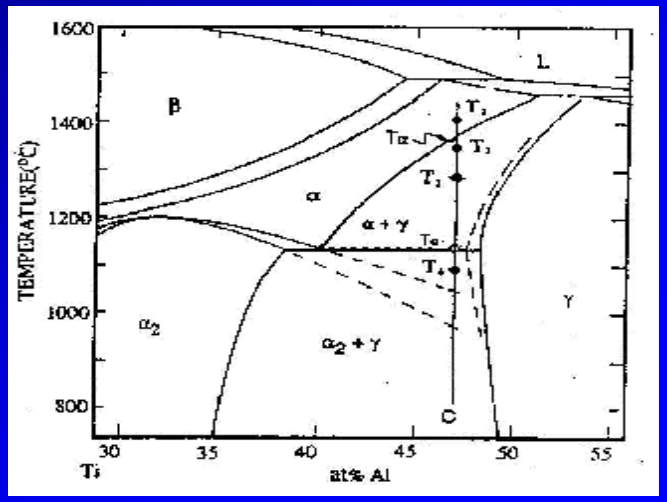
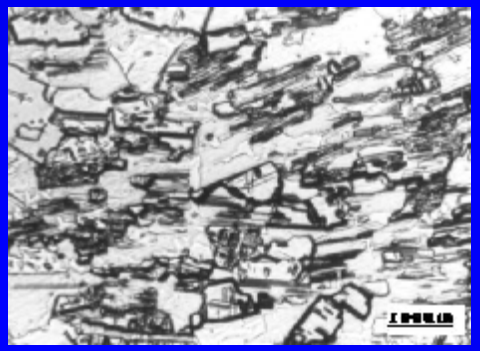
Approaches to improve the ductilty





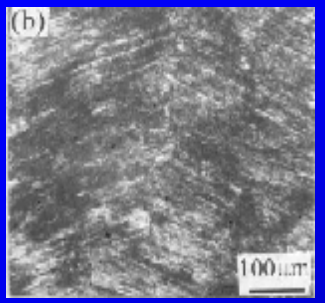
Cast DP obtained by annealing at T_3

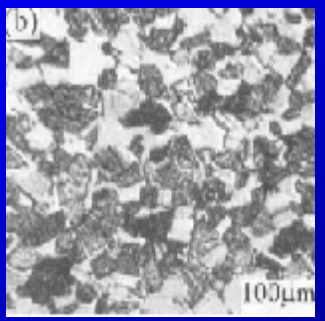
Cast fine lamellar microstructure

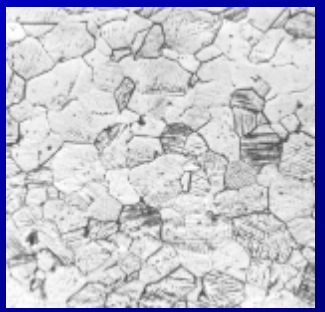
A cast lamellar colony

A gamma grain after annealing

Regained finer lamellar colonies







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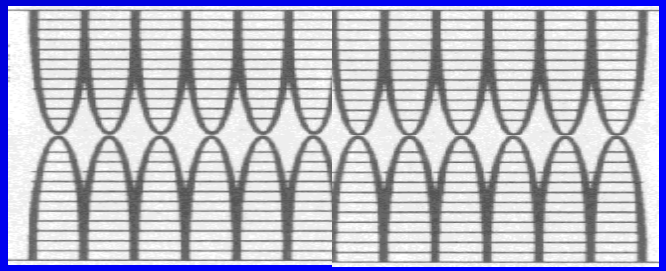
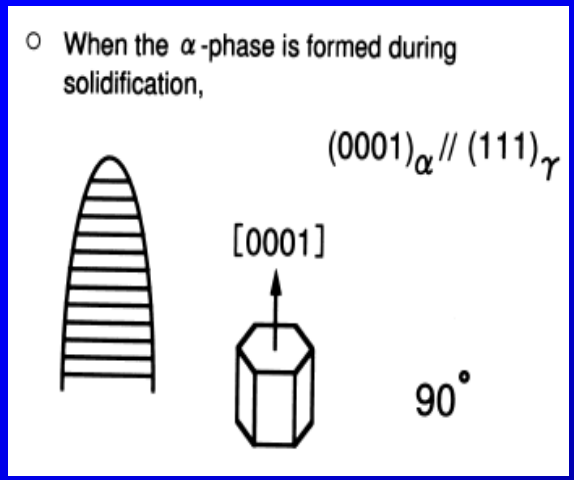
Approaches to improve the ductilty

A way specific to the blades application



- When the α-phase is formed during solidification,



Textured lamellar microstructures similar to PST crystals will be formed if fully a columnar crystals could be produced during solidification. It is therefore called self-oriented lamellar (SOL) microstructure

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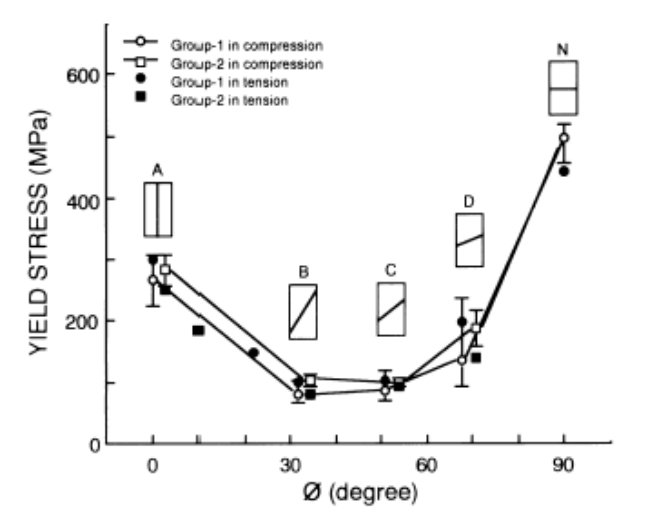
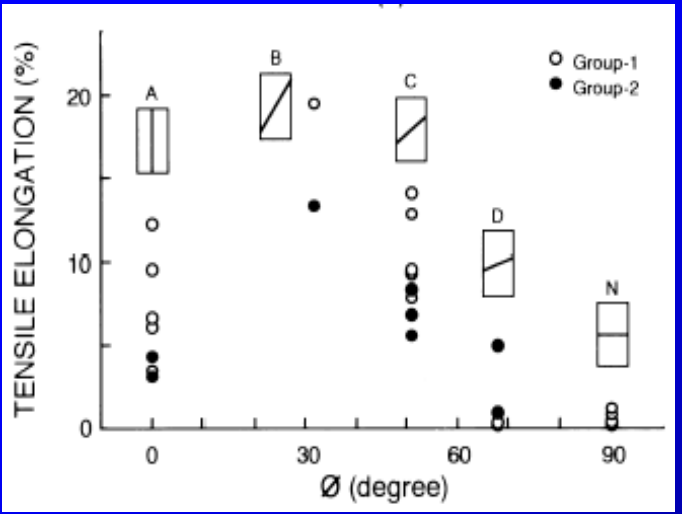
Approaches to improve the ductilty

A way specific to the blades application





The mechanical characters of this lamellar microstructure can be expected similar to PST in principle

Development of Desired Microstructure

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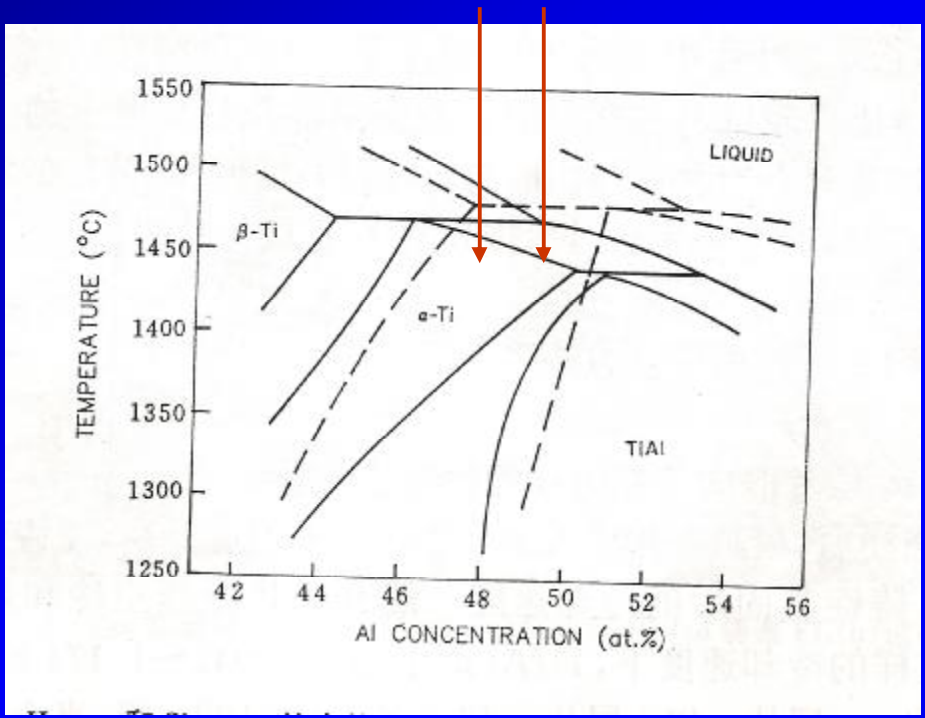

$L - L+b - b+a - a - a+g - a_2+g$

b transforms to a phase following Burgers' relation {1 1 0}//(0 0 0 1)

$L - L+a - a - a+g - a_2+g$

g plates precipitate in the a phase following {1 1 1}g//(0 0 0 1)a orientation

Desired solidification route

$$L - L+a - L+a+g_p - a+g_p - (a+g_s)_L+g_p - (a_2+g_s)_L+g_p$$

Development of Desired Microstructure

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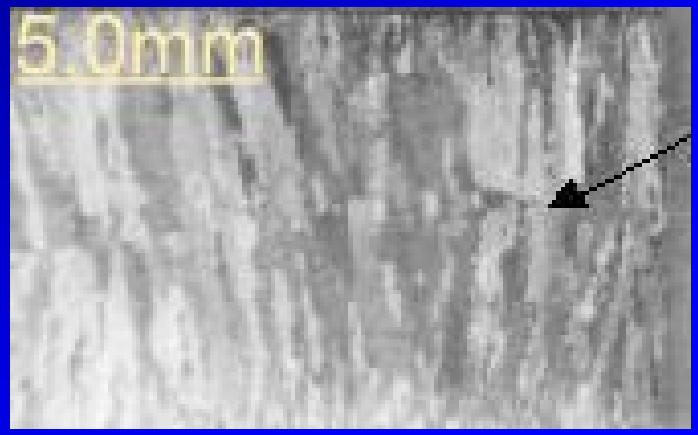
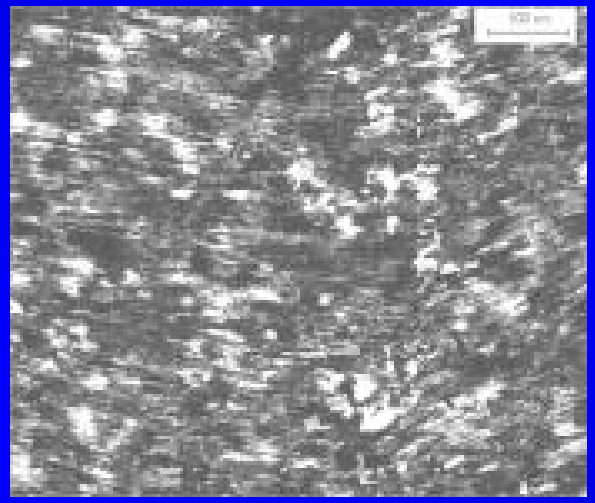


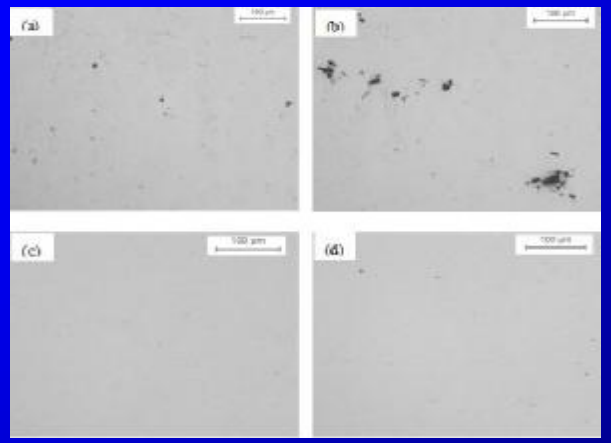


Key points:

Ti/Al ratio at 1.03 – 1.07

Controlled cooling rate

Remove pores by HIP



As-cast

HIPed

surface Center

Mechanical Evaluation and Discussion

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	d(mm)	V_L(%)	σ_b(MPa)	δ_5(%)	K_{1C}(MPa√m)	$\sigma_{b,800C}$(MPa)
SOL		98	550	2.0	*24 (K_Q)*	550
RFL	100	99	450	3.1	20.2	360
FFL#	45	99	502	3.5	21.1	390
NL#	203	77	460	1.4	23.0	410
FL#	505	100	405	0.8	25.4	400

Those obtained in wrought TAC-2 alloy

Mechanical Evaluation and Discussion

Of SOL Microstructure

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Batch	Amb. Tension	Measured Values			Average
1	σ_b (MPa)	545	550	565	553
	δ_5 (%)	2.0	2.0	2.0	2.0
2	σ_b (MPa)	540	545	515	533
	δ_5 (%)	2.5	2.0	2.0	2.2
3	σ_b (MPa)	555	550	—	553
	δ_5 (%)	2.0	2.5	—	2.2

	Property	Measured Values			Average
Amb. notch tension (R=0.2)	σ_{bN} (MPa)	675	680	685	680
	$q_t = \sigma_b / \sigma_{bN}$	0.82	0.81	0.81	0.81
Fracture Resistance	K_Q （MPaÖm）	23	24	25	24

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Mechanical Evaluation and Discussion

Of SOL Microstructure

	Properties	Measured value			Average
800℃ tension	σ_b (MPa)	555	555	560	557
	δ_5 (%)	14.0	12.0	9.0	11.5
800℃ creep rupture	$\sigma_{800℃\ 100h}$（MPa）	200	—	—	—
750℃ fatigue (R=0.5，N=10^7)	σ_N （MPa）	240	—	—	—
750℃ Creep (200Mpa/100h)	deformation (%)	0.25	—	—	—

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Mechanical Evaluation and Discussion

Two points SIEMENS interested

- The strength and ductility can be retained after the tensile specimens being exposed at 700°C for 100 hrs.

  -540 MPa and 1.5% plastic elongation

- Exhibit a positive tensile notch sensitivity even when the notch radius being smaller than 0.2 mm.

Mechanical Evaluation and Discussion

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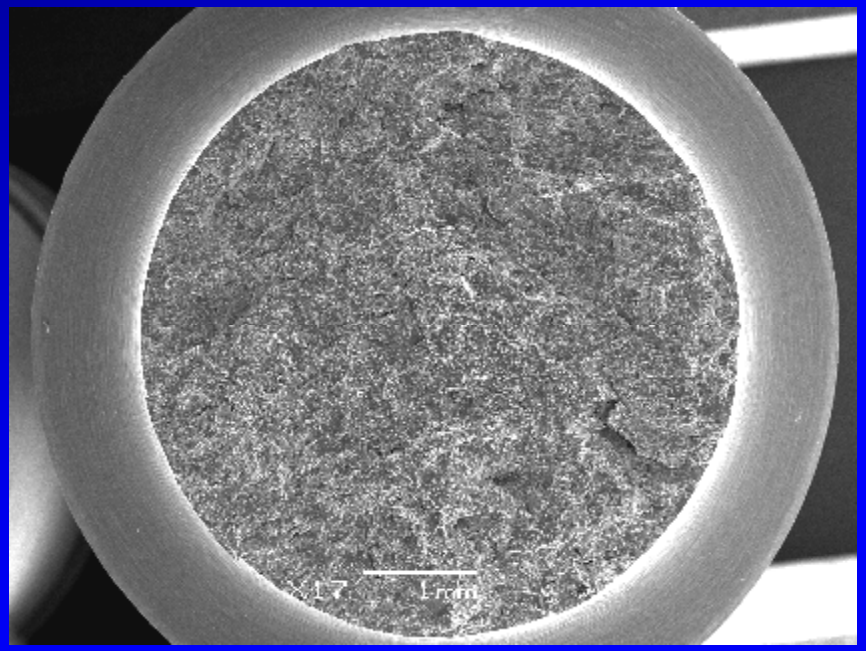

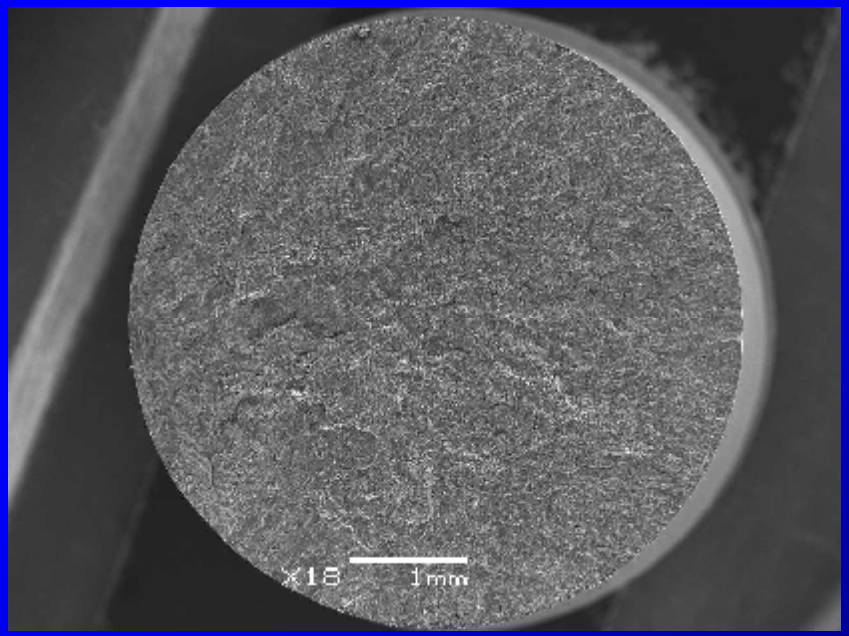

Different from the normal tensile fracture surface, that of notched specimens (left) showed a clear fibrous region

Mechanical Evaluation and Discussion

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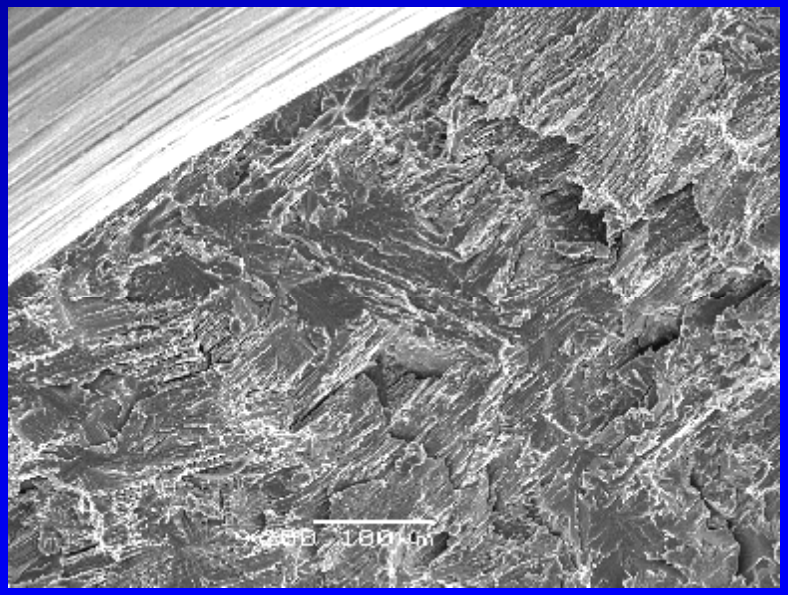

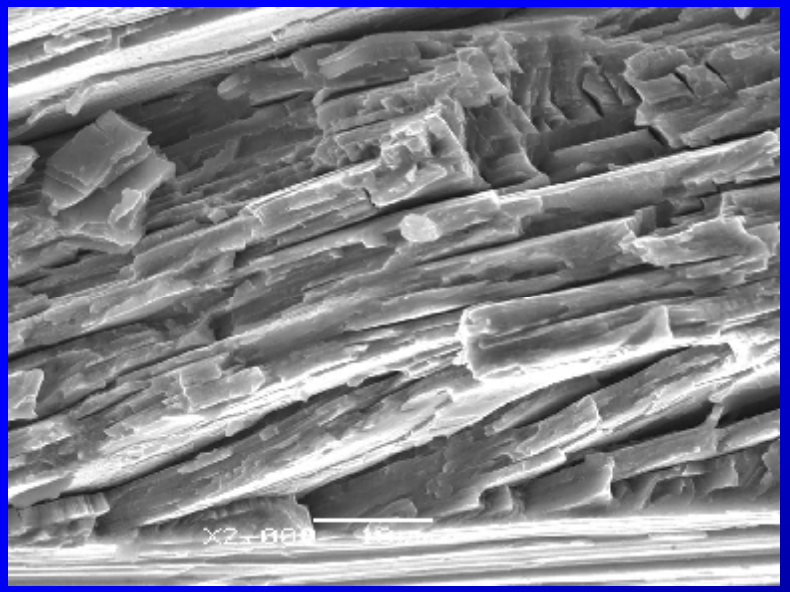

The fibrous region consists of large amount of micro-cracks and secondary cracks, those are believed to release the stress concentration introduced by the notch tip during tension

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Summary and discussion

The cast textured lamellar microstructure shows improved mechanical properties compared with refined cast TiAl, even higher strength level than the wrought alloys. The mechanical superiority comes from the preferential lamellar orientation.

It is a strong potential to improve the mechanical properties of cast TiAl alloys specific to the application for industrial turbine blades.

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Thanks for Attention