

➤ Single crystal Ni-based alloys - Part 1:

You recently joined an Aerospace company as a material expert, and you are responsible for the selection, processing and characterization of high-performance Ni and Ti alloys

- a) Your team leader gave you the following scanning electron micrograph (Figure 3), which shows the cross section of a single crystalline turbine blade of the alloy CMSX-4 after 1'000 h of service with a maximum temperature of 950°C in an aero-engine. The alloy has the composition (in wt.%) given in Table 2.

Table 2: Chemical composition of CMSX-4;

Ni	Cr	Co	Mo	Al	Ti	Ta	Hf	Re
Bal.	6.5	9	0.6	5.6	1.0	6.5	0.1	3.0

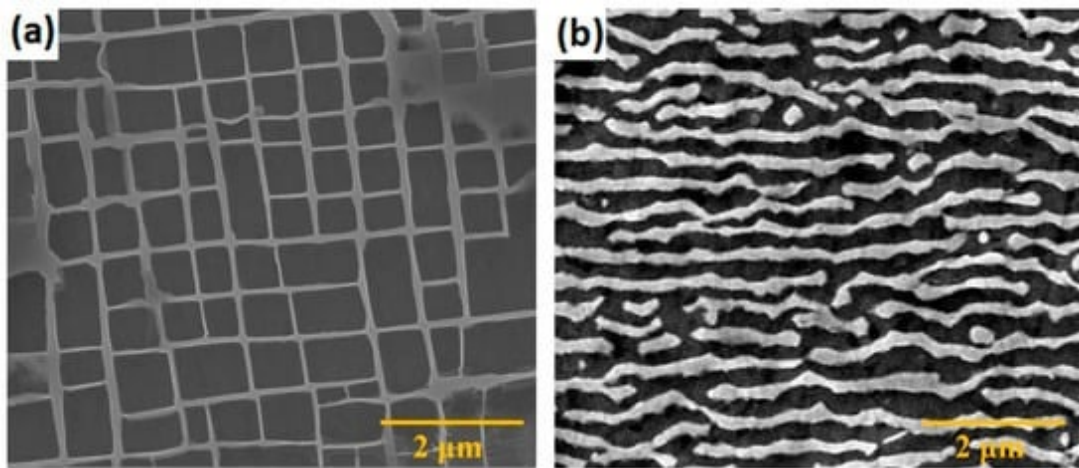


Figure 3. SEM – Cross section of a single-crystal turbine blade before and after 1'000 h of operation

- Name the phases that can be seen in the micrograph.
- Explain the role of the alloying elements Cr and Re.

- Explain the microstructural changes that can be observed between the two micrographs. What is the common name for this phenomenon?

- b) Your team leader shares the results from stress rupture tests performed at different test parameters on Ni-based super alloy used for turbine blades (shown in Figure 4). Consider that $LMP = T (\ln(t) + c) \times 10^{-3}$ and that the Larson miller parameter constant c is 25.

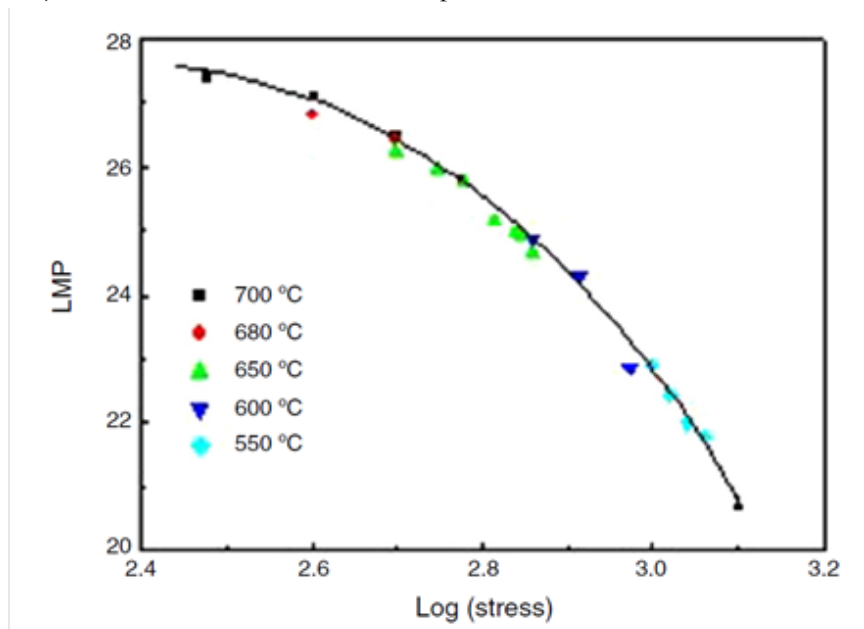


Figure 4. Larson Miller Parameter (LMP) correlation with stress obtained from stress rupture test of Ni-based super alloy.

- What stress can be applied so that the service life of the alloy at 500°C is 6000 h.
- Additionally, your team leader wishes to have a safety factor of 10% considering the testing uncertainty. What will be your suggested stress for application of the alloy at 500°C is 6000 h?

➤ Complementary exercise 1

- a) Figure 5-a shows a single-crystalline (SX) turbine blade, which was made from the Ni-based superalloy CMSX-4 using the Bridgman furnace process (schematic Figure 5-b). During the casting process, the withdrawal velocity was set to 20 mm/min and the thermal gradient at the solid/liquid interface was set to 2500 K/m.

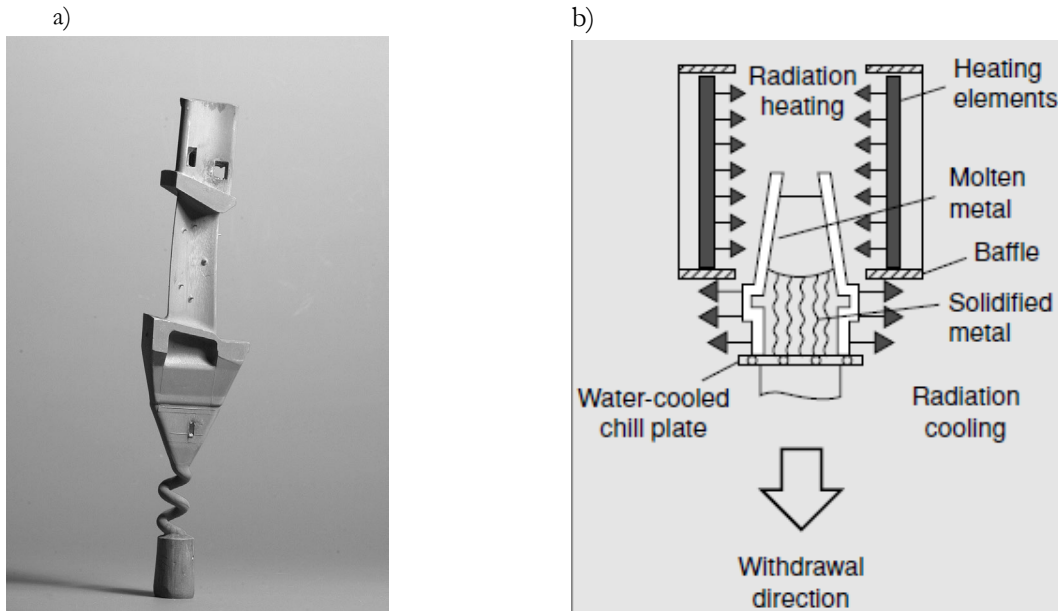


Figure 5: a) Single-crystalline turbine blade; b) schematic of the Bridgman furnace process;

- Explain the function of the 'pig-tail' in the lower part of the cast turbine blade.
- Name and briefly explain two typical casting defects that would occur when increasing the withdrawal velocity to 40 mm/min.

- b) After casting, components fabricated from single-crystal superalloys undergo a complicated heat treatment designed to remove the microsegregation inherited from the casting process.
- Explain briefly why microsegregation occurs during casting of Ni superalloys.
 - What would be the implications of not heat-treating the cast components?

- c) Creep samples from the single-crystal superalloys TMS-75 and TMS-82+ alloys were cast such that the compositions of the γ and γ' -Ni₃Al phases were on a common tie-line, so that the phase compositions remain invariant. The compositions of the two alloys (in wt.%) are given in Table 3. Figure 6 shows the creep rupture life of the two alloys as a function of the fraction of the γ' phase present at 900°C and at 1100°C.

Table 3: Chemical compositions of TMS-82+ and TMS-75 (in wt.-%);

Alloy	Co	Cr	Mo	W	Al	Ti	Ta	Hf	Re	Ni
TMS-82+	7.8	4.9	1.9	8.7	5.3	0.5	6.0	0.1	2.4	Bal.
TMS-75	12.0	3.0	2.0	6.0	6.0	-	6.0	0.1	5	Bal.

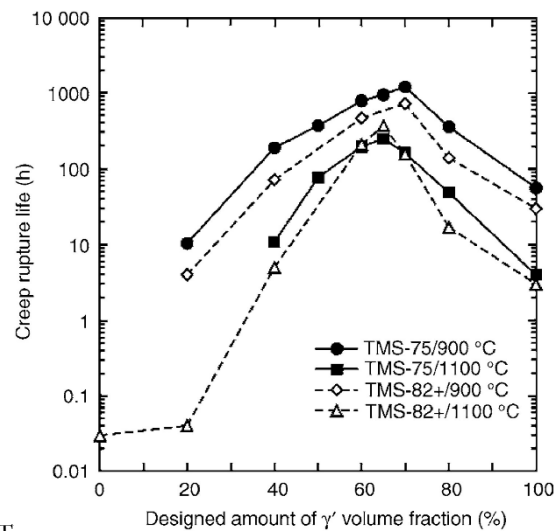


Figure 6: Creep rupture life of TMS-75 and TMS-82+ as a function of the fraction of the γ' phase ($\sigma = 392$ MPa @ $T = 900^\circ\text{C}$, $\sigma = 137$ MPa @ $T = 1100^\circ\text{C}$);

- Explain the general shape of the curves, i.e. the first increasing and then again decreasing creep rupture life with increasing γ' phase fraction. Why is the maximum creep resistance not imparted at a 50% fraction of γ' phase?
- Explain the in general higher creep rupture life of the TMS-75 alloy at γ' phase fractions below 60 vol%.

d) Figure 7 shows the binary Ni-Al phase diagram.

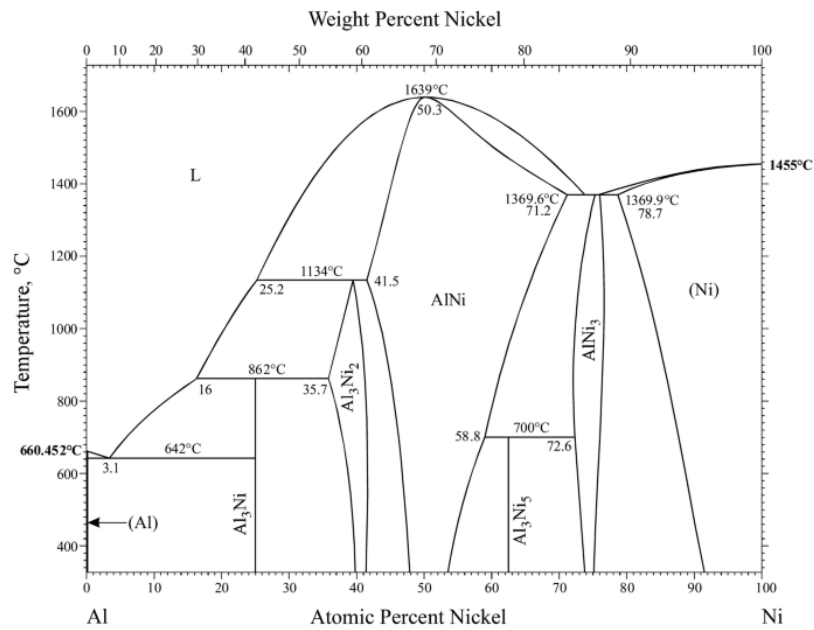


Figure 7: Binary Ni-Al diagram;

- Give two reasons why alloys with a composition of approximately 50 at.% Ni and 50 at.% Al are of interest as a replacement for Ni superalloys for high-temperature applications such as turbine blades.

- Is the phase NiAl a Laves phase? Justify your answer.

- Explain why pure NiAl exhibits a poor ductility and, as a result, a high notch sensitivity at temperatures below 650°C.
- As a result of this low ductility, shape forming of NiAl using e.g. milling or turning is extremely challenging. Name and briefly explain an alternative method that could be used to fabricate parts with more intricate geometries such as turbine blades.