Advanced Metallurgy – Exercise 3 – 16/10/2024

➢ Creep behavior of Ni-based alloys:

A turbine blade for an aircraft engine is made of the Ni alloy CM 247 LC with the composition reported in Table 1 and a density of 8.54 g/cm^3. The blade dimensions are 70*15*2 cm^3 (Figure 1), the rotation speed is 3000 rpm, and the working temperature is 800 °C.

a) Define the centrifugal force and, therefore, the stress to which the blade is subjected during the service assuming a point mass located at the extremity of the blade.

b) The service life of turbine blades is on the order of years. Therefore, the collection of creep data is impractical from normal laboratory tests for prolonged exposures. One solution to this problem involves performing creep and/or creep rupture tests at temperatures that are higher than the actual service temperatures, for shorter time periods, and at a comparable stress level, and then making a suitable extrapolation to the in-service condition. A commonly used extrapolation procedure employs the Larson–Miller parameter, defined as:

$$LMP = T(C + \log(t)) \tag{1}$$

where LMP is the Larson-Miller parameter, T the temperature, C a constant of the material (normally equal to 20) and t is the time to rupture. The Larson-Miller relation shows that a material is thought to exhibit a particular Larson-Miller parameter for a given applied stress and the rupture life of a sample at a given stress level will vary with test temperature in such a way that the Larson-Miller parameter remains unchanged. Derive the Larson-Miller relation (Equation 1)

Hint: $\dot{\varepsilon} \propto (\frac{1}{t})$

c) Using the Larson-Miller diagram in Figure 2, define the lifetime of the blade of point a.

d) Define the variation of the time to rupture if:
•The working temperature decreases to 750°C (rpm: 3000)
• The rotation speed increases to 3500 rpm (T = 800°C)

e) Table 1 reports the composition of four different Ni-superalloys. Explain the variation in the Larson-Miller diagrams observed in Figure 2 for the four different alloys.

f) The IN738 (density of 8.11 g/cm^3) is used for the blade production.
•Which maximum temperature can be reached to achieve the same lifetime of point a but using the alloy IN738 (rpm: 3000)?
• Define which rotation speed can be reached to achieve the same lifetime of point a but using the alloy IN738 (T = 800°C).

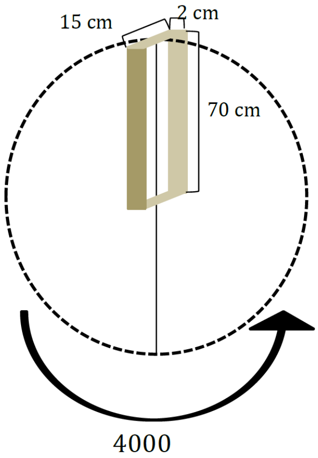

Figure 1: Dimensions of the blade.

Table 1: Chemical composition of different Ni alloys.

Alloy	Cr	Co	Mo	W	Ta	Nb	Al	Ti	C	B	Zr	Others
CM 247 LC	8.1	9.2	0.5	9.5	3.2		5.6	0.7	0.07	0.01	0.01	1.4 Hf
IN 738 LC	16	8.5	1.7	2.6	1.7	0.9	3	3	0.11	0.01	0.05	
IN 738	16	8.5	1.7	2.6	1.7	0.9	3	3	0.17	0.01	0.1	
Rene 80	14	9.5	4	4			3	4.8	0.17	0.015	0.03	

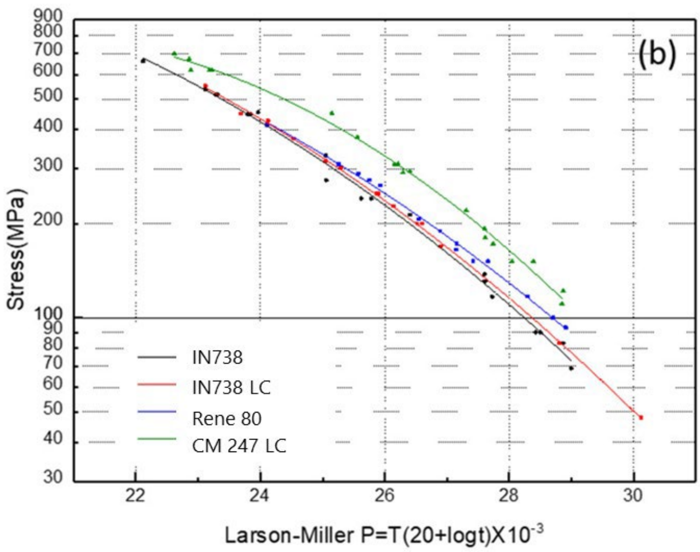

Figure 2: Larson-Miller diagram for different Ni-alloys.

➢ 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 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 1: 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

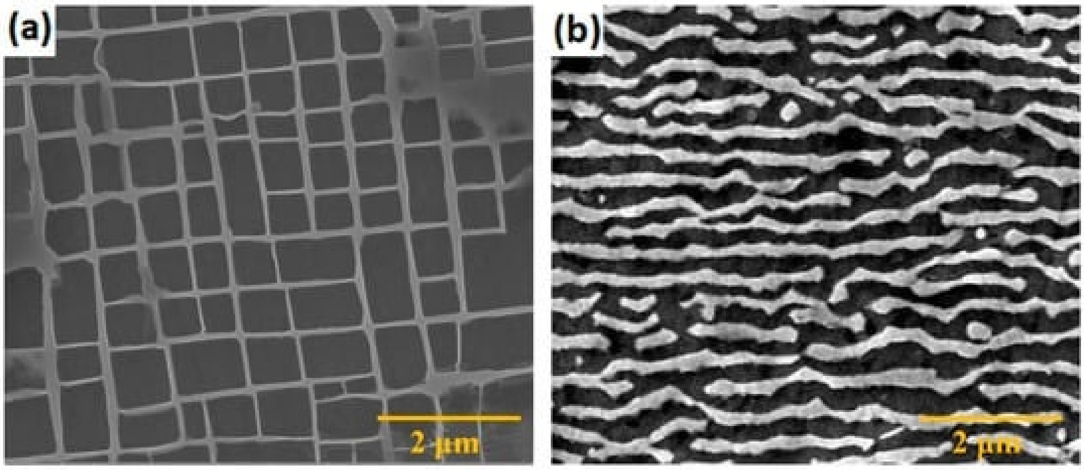

Figure 3. SEM – Cross section of a single-crystal turbine blade before and after 1'000 h of operation.

- 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) × 10^{-3} and that the Larson miller parameter constant c is 25.

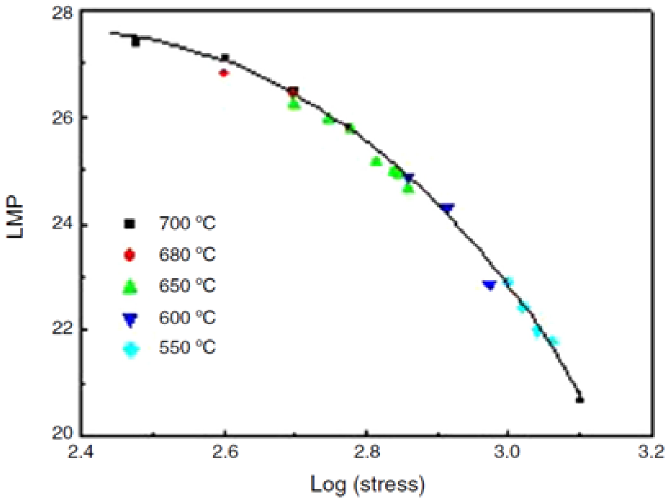

Figure 4. Larson Miller Parameter (LMP) correlation with stress obtained from stress rupture test of Ni-based super alloy.

- 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?

➢ Single crystal Ni-based alloys - Part 2:

The defect-free fabrication of single crystal turbine blades depends, among other parameters, on the withdrawal velocity of the casting mold from the hot part of the casting furnace, which must be kept within tight margins. An SX turbine blade is to be manufactured from the Ni alloys CMSX-4 with a chemical composition given in Table 3. The alloy has a mass-related heat of solidification ΔH of 230 J/g, a density ϱ of 8.7 Kg/dm^3 and a thermal conductivity in the solid state λ of 20 $W/K.mm^3$. The mold is placed in a Bridgman furnace as shown in Figure 5. In the cold part of the furnace, the heat is dissipated only by radiation so that a constant temperature gradient (G) of 2 k/mm in the solidification range of the turbine blade is achieved.

a) Estimate the maximum withdrawal (or solidification) velocity so that a single crystal turbine blade is obtained.

Hints:

I. Consider that the blade is rod-shaped with a constant diameter d.
II. Consider the balance of the latent heat of solidification and the heat dissipation in the cold part of the furnace.

b) What defects may occur in the turbine blade if this withdrawal velocity is exceeded?
c) How can the withdrawal velocity be increased so that a higher productivity of the process is achieved?

Table 3: Chemical composition of CMSX 4 Ni alloy.

Alloy	Cr	Co	Mo	W	Ta	Nb	Al	Ti	Re	C	B	Zr	Hf
CMSX 4	6.5	9	0.6	6	6.5		5.6	1	3				0.1

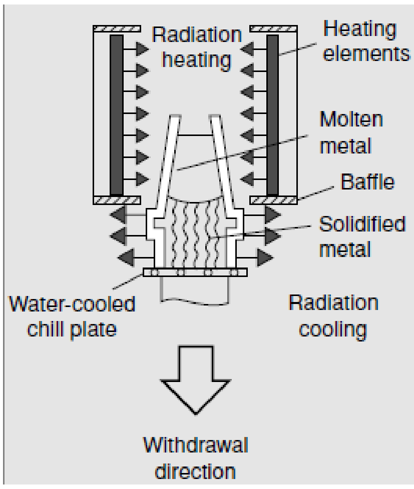

Figure 5: Schematic structure of a single-crystal casting plant based on the Bridgman principle.

The solutions of this exercise will be available on Moodle from next exercise session.

Please contact us if you spot any errors or have questions:

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