DYNAMIC RECRYSTALLIZATION (DRX)

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RECRYSTALLIZATION

- **Recrystallization is an important process in the creation of strain-free grains in metals. When a metal is subjected to plastic deformation, such as rolling or forging, it can create dislocations and can cause the metal to become harder and stronger .**

- **Recrystallization involves heating the metal to a temperature below its melting point but high enough to promote the formation of new crystal structures. As the metal cools, the new crystal structures grow and consume the dislocations, resulting in a strain-free grain structure.**

DYNAMIC VS STATIC

TYPES	STATIC RECRYSALLIZATION	DYNAMIC RECRYSALLIZATION
DEFINITION	Recrystallization that occurs at a constant temperature and strain rate	Recrystallization that occurs during deformation
STRAIN RATE	It generally occurs at lower temperatures and strain rates.	It generally occurs at higher temperatures and strain rates.
MICROSTRUCTURE	Static recrystallization typically produces larger, more equiaxed grains with more uniform sizes and shapes	Dynamic recrystallization produces smaller, more refined grains with more irregular shapes and sizes.

TYPES OF DYNAMIC RECRYSTALLIZATION

1.Discontinuous Dynamic Recrystallization

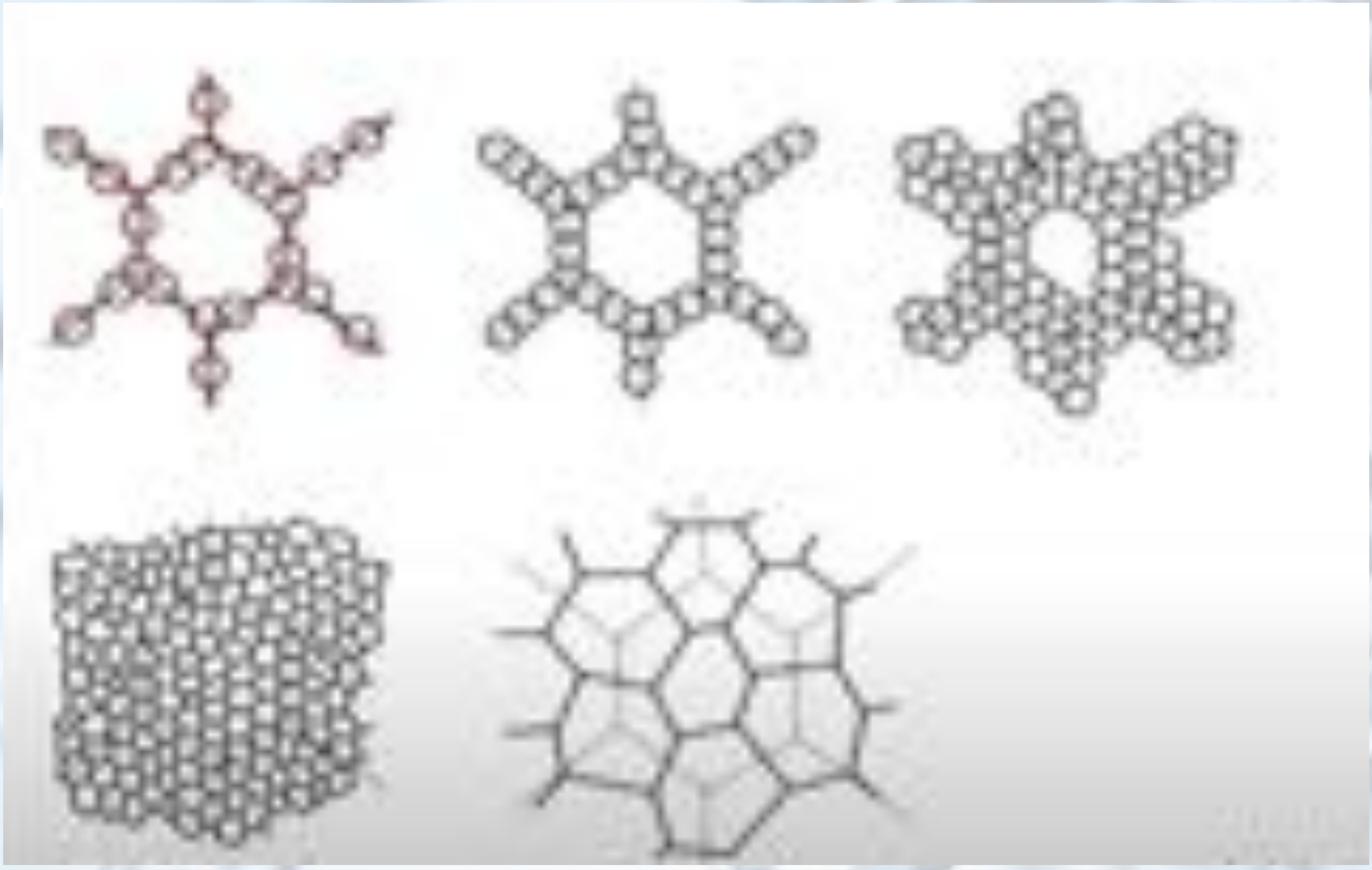
- Discontinuous dynamic recrystallization (DDRX) is common in materials with low stacking-fault energy.

- It is characterized by the formation of discrete, small-sized grains that are separated by high-angle grain boundaries.

- DDRX occurs at relatively low strain rates and high temperatures, typically in the range of 0.01 to 10 s-1 and 0.5 to 0.8 times the melting point in Kelvin, respectively.

- DDRX occurs in regions of high accumulated dislocation density and is driven by the difference in stored energy between the heavily deformed regions and the relatively undeformed regions.

MICROSTRUCTURE EVOLUTION



2. Continous Dynamic Recrystallization

- **Continuous dynamic recrystallization is common in materials with high stacking-fault energies.**

- **It occurs when low angle grain boundaries form and evolve into high angle boundaries, forming new grains in the process.**

- **In CDRX, new grains form continuously and homogeneously throughout the deformed material. This results in a fine, equiaxed grain structure with relatively uniform grain size and low angle boundaries.**

- **The process occurs at high strain rates and low temperatures, typically in the range of 10 to 1000 s-1 and below 0.5 times the melting point in Kelvin, respectively.**

2. Continous Dynamic Recrystallization

There are three main mechanisms of continuous dynamic recrystallization:

- **First, continuous dynamic recrystallization can occur when low angle grain boundaries form and evolve into high angle boundaries.**

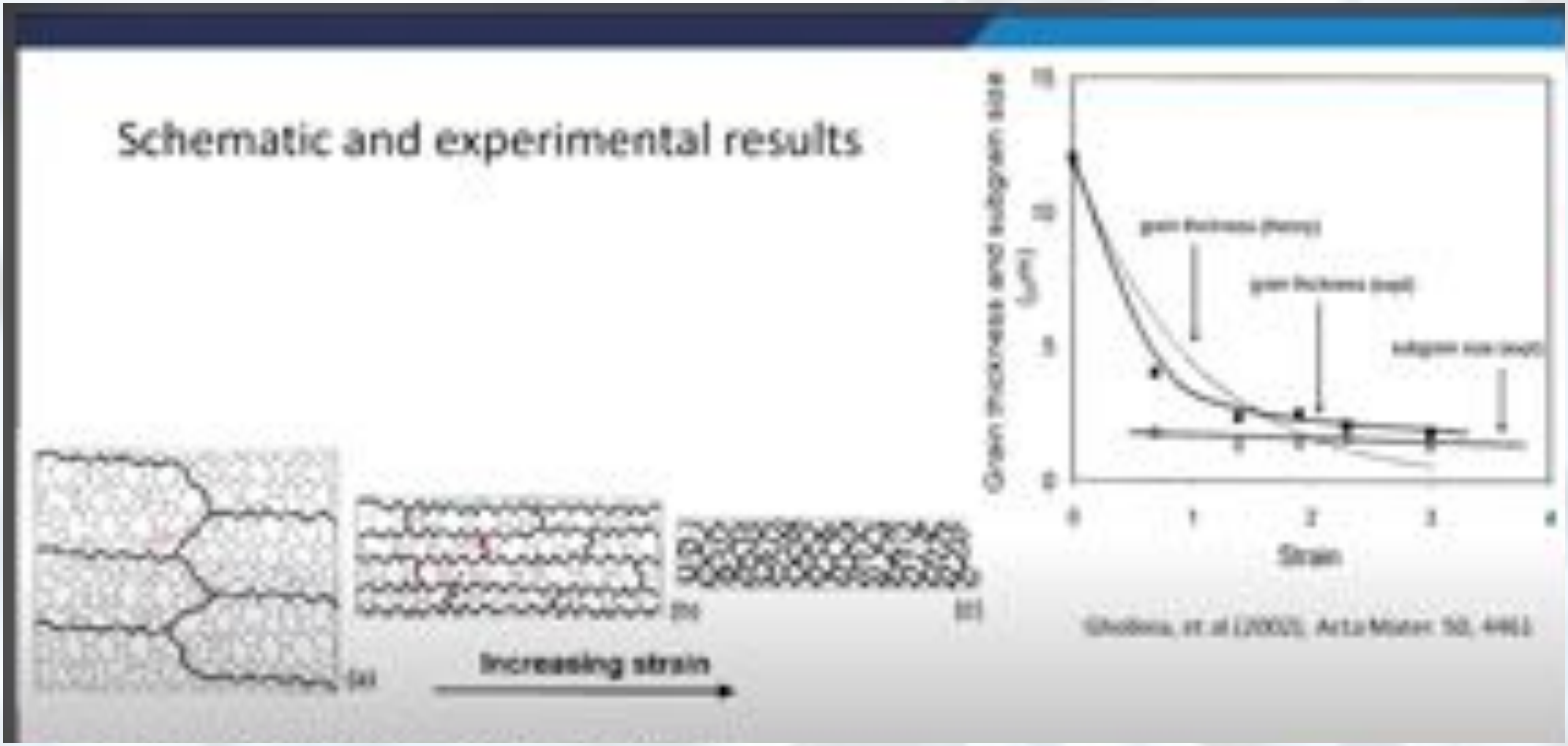
- **Second, continuous dynamic recrystallization can occur through subgrain rotation recrystallization; subgrains rotate increasing the misorientation angle. Once the misorientation angle exceeds the critical angle, the former subgrains qualify as independent grains.**

- **Third, continuous dynamic recrystallization can occur due to deformation caused by microshear bands.**

3. Geometric Dynamic Recrystallization (GDRX)

- Geometric dynamic recrystallization is common in materials with high stacking-fault energies.
- Migration of HAGBs to form serrations , serrations are developed during hot deformation , with a wavelength similar to subgrain size.
- Significant grain elongation and thinning takes place .
- Very high strain must be imposed

3. Geometric Dynamic Recrystallization (GDRX)



FACTORS

STRAIN RATE

GRAIN SIZE

ZENER HOLLOMAN PARAMETER (Z)

TEMPERATURE

STRAIN RATE

- The high strain rate provides little time for recovery processes such as annihilation or climb, and dislocations accumulate, leading to higher dislocation density. Subsequent shear deformation breaks up the subgrains and generates new grain boundaries which leads to the formation of new grains.

- The rate of dynamic recrystallization generally increases with increasing strain rate until a maximum recrystallized fraction is reached.

- At higher strain rates, the dynamic recrystallization process can lead to a finer and more homogeneous microstructure, resulting in improved strength and toughness.

GRAIN SIZE

- . At high temperatures and low strain rates, dynamic recrystallization can lead to the formation of larger grains.
- However, at high strain rates, dynamic recrystallization can result in finer grains due to the breaking up of the subgrains formed during the deformation process.
- In general, a smaller grain size can result in higher strength and improved toughness. This is because the smaller grains reduce the size of the regions where cracks can propagate, and increase the number of grain boundaries that can arrest crack propagation.
- However, excessively small grains can also lead to reduced ductility, as the high number of grain boundaries can act as sites for crack initiation.

TEMPERATURE

- Dynamic recrystallization (DRX) is a temperature-dependent process that occurs in metals and alloys during plastic deformation at elevated temperatures.
- The temperature range where DRX occurs depends on the material, but typically falls between 0.5 and 0.8 of the melting point in Kelvin
- If the temperature increases, dynamic recrystallization (DRX) in metals and alloys tends to occur more readily and at lower strains.
- However, at very high temperatures, above the melting point, the material may undergo partial or complete melting instead of DRX

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Zener hollomon parameter(Z)

$$Z = c \exp(Q/RT)$$

c=strain rate Q=activation energy

R=gas constant T=absolute temperature

- When the bulging occurs subgrains will form and subgrain will be surrounded by what kind of boundaries that would depend on Z:

- At high z strain rate will be high and temperature will be low, then subgrains will be associated with the sub grain boundaries.
- At low z temp will be high and strain rate will be low then subgrains will be surrounded by twin boundaries.
- Subgrains boundary are basically low angle grain boundaries.
- If this condition is not satisfied i.e condition of high Z then low angle grain boundaries will not form rather we can have twin boundaries ,so at low Z, low strain rate and high temp ,subgrains will be bounded by twin boundary.
- Driving force for bulging– dislocation density gradient develop near the original grain boundary.

SIGNIFICANCE OF DYNAMIC RECRYSTALLIZATION

- **Improved formability**: improve the formability by reducing the amount of force required to deform it. This is particularly important in manufacturing processes where materials need to be shaped or formed.
- **Better homogenization**: homogenize the microstructure of a material, reducing the risk of local inhomogeneities that can lead to cracking and failure.
- **Optimization of processing parameters:** to optimize the processing parameters such as deformation temperature, strain rate, and grain size distribution to obtain the desired microstructure and properties of the material.
- **Elimination of defects**: DRX can help to eliminate defects in a material, such as dislocations and voids, which can improve the material's mechanical properties and reduce the risk of failure.

LIMITATION OF DYNAMIC RECRYSTALLIZATION

- **Difficulty in controlling the process:** DRX can be difficult to control because it depends on a number of factors, such as temperature, strain rate, and strain level.

- **Risk of grain growth:** DRX can result in grain growth, which can reduce the mechanical properties of the material.

- **Limitations in materials:** DRX is not suitable for all materials, and some materials may not exhibit DRX even at high temperatures.

- **Cost:** The equipment and facilities required for DRX can be expensive, which can increase the cost of manufacturing.

- **Processing time:**Processing time: DRX can require significant processing time, especially for larger workpieces or more complex geometries. This can increase the cost and time required for producing a finished product.

PROCESSING MAPS

WHAT ARE PROCESSING MAPS?

Processing Maps

When a metallic alloy is subjected to deformation at high temperatures, it may undergo microstructural changes through different mechanisms. Some of these (e.g., dynamic recrystallisation and dynamic recovery) are known to be “safe” mechanisms, while others (e.g., void formation and wedge cracking) lead to the formation of defects. Processing maps depict the hot workability of an alloy by combining information about the ease with which its microstructure changes upon deformation with delineated regions of the unstable flow. They can be helpful in assessing the ideal processing conditions that ensure a defect-free final product. **The processing map is the superimposition of a power dissipation map and instability map.**

POWER DISSIPATION MAPS

- Power dissipation maps are used to understand the distribution of heat in different materials or structures.
- When a material is subjected to a changing electric field or magnetic field, it generates heat due to the resistance of the material.
- Power dissipation maps can be used to visualize where the heat is being generated in the material.
- Power dissipation maps can also be used to study the behavior of materials under different conditions, such as high temperatures. This information can be used to design new materials or to optimize existing materials for specific applications.

POWER DISSIPATION MAPS

At a given temperature in the hot working regime, the rate of dissipation work (power) is directly proportional to the rate of internal entropy production which is always positive since the process is irreversible

$$P = \overline{\sigma} \cdot \dot{\overline{\varepsilon}} = \theta \cdot \frac{d^{(i)}S}{dt} \geq 0$$

where σ is the effective stress, & ε ' is the effective strain rate, θ is the temperature and dS/dt is the rate of internal entropy production
The total rate of entropy production consists of two complementary parts. The first part consists of "conduction entropy" which is due to the conduction of heat from where it is generated (due to plastic flow) to the colder parts of the body. The second part is due to a microstructural dissipation which lowers the flow stress for plastic flow (dislocation movement).

MATERIAL FLOW INSTABILITIES DURING HOT DEFORMATION

On the basis of Raj maps, the deformation characteristics of materials are interpreted as follows.

- In the low temperature (T ≤ 0.25Tm), high strain rate regime (10–100 s−1), void formation occurs at hard particles leading to ductile fracture.
- In the high temperature (T ≥0.75Tm), low strain rates (≤10−3 s−1) regime, wedge cracking caused by grain boundary sliding occurs (except in superplastic materials in which wedge cracking is at a minimum).
- In high temperature (Tm ≈ 0.75) and high strain rate regime (10−1 to 10 s−1), dynamic recrystallization occurs in low stacking fault energy materials.
- At very high strain rates (≥10 s−1) there is a possibility for the occurrence of adiabatic shear bands and these lead to flow localization.
- Out of all the above mechanisms, DRX and superplastic deformation are 'safe' mechanisms for hot working while dynamic recovery is preferred for warm working. All other mechanisms either cause microstructural damage or inhomogeneities of varying intensities and hence are to be avoided in the microstructure of the component

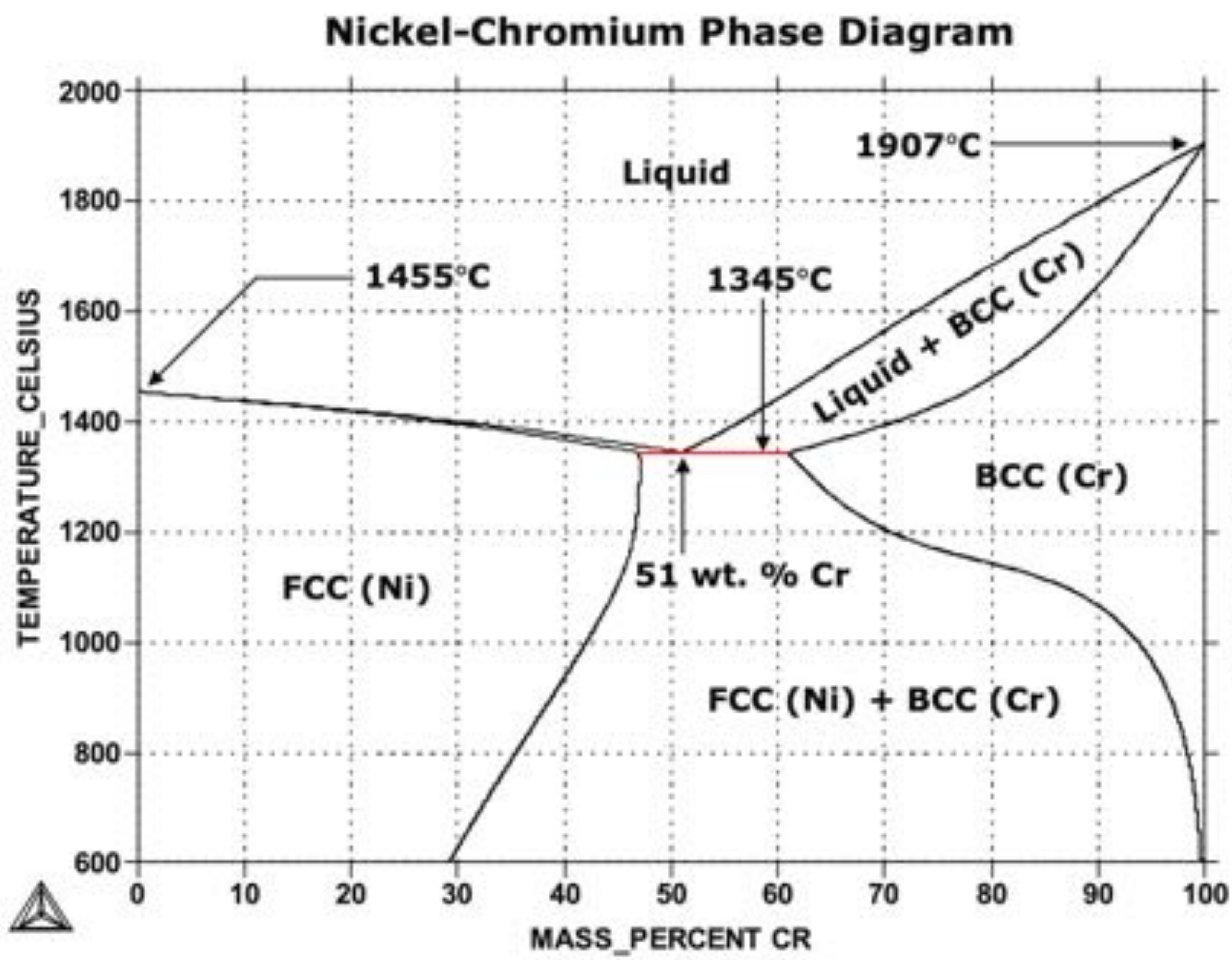
HOW TO IDENTIFY THE INSTABILITY REGIONS

Instability parameter

$$\xi(\dot{\varepsilon}) = \frac{\partial \ln[m/(m+1)]}{\partial \ln \dot{\varepsilon}} + m < 0$$

The following microstructural features are helpful in identifying them:

- **The adiabatic shear bands occur as intense flow localization at 45° with respect to the compression axis.**
- **Within the band, cracking or recrystallization or phase transformation may occur.**
- **Under intense flow localization conditions, the bands may have a 35° orientation with respect to the compression axis.**
- **The kink bands have their axis along the applied compressive stress while the tensile fractures of the specimens deformed in the dynamic strain aging region occur at 45° with respect to the tensile axis.**


Nickel-Chromium Phase Diagram
Liquid
1907°C
1455°C
1345°C
Liquid + BCC (Cr)
BCC (Cr)
FCC (Ni)
51 wt. % Cr
FCC (Ni) + BCC (Cr)
TEMPERATURE_CELSIUS
MASS_PERCENT CR
2000
1800
1600
1400
1200
1000
800
600
0
10
20
30
40
50
60
70
80
90
100

OVERVIEW

The experiment aims to analyse the processing maps for NI-Cr alloy.

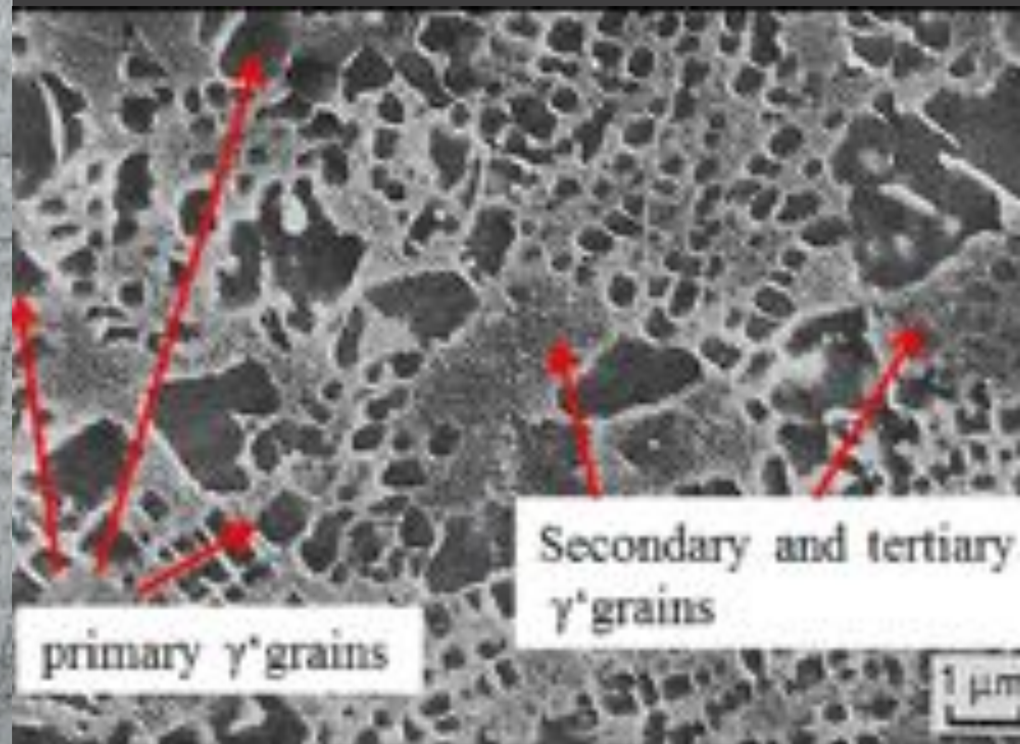
The nickel-chromium system reveals that chromium is fairly soluble in nickel. It has a maximum soluble rate of 47%, which then decreases to approximately 30% at room temperature. Several commercial alloys are based on this solid solution. These alloys have superior resistance to high-temperature corrosion, oxidation, and optimal wear resistance.

Commercial alloys mainly contain 20–30% Cr to stabilize a protective chromia scale and always contain several minor additions to improve their mechanical and/or chemical properties: typical ‘Nichrome’

IN-100

- **Material: IN-100**
- **Composition:**
- **Cr-12.0, Co-18.9, Mo-3.15, Nb0.02, Al-5.1, Ti-4.2, B-0.02, Zr- 0.06, V-1.8, C-0.07, Ni-bal.**
- **Prior History: Argon gas atomized powder (150   m) hot isostatically pressed at 1200o C for 3 hour at 115 MPa. Average grain diameter-23um.**

MICROSTRUCTURE



MICROSTRUCTURE

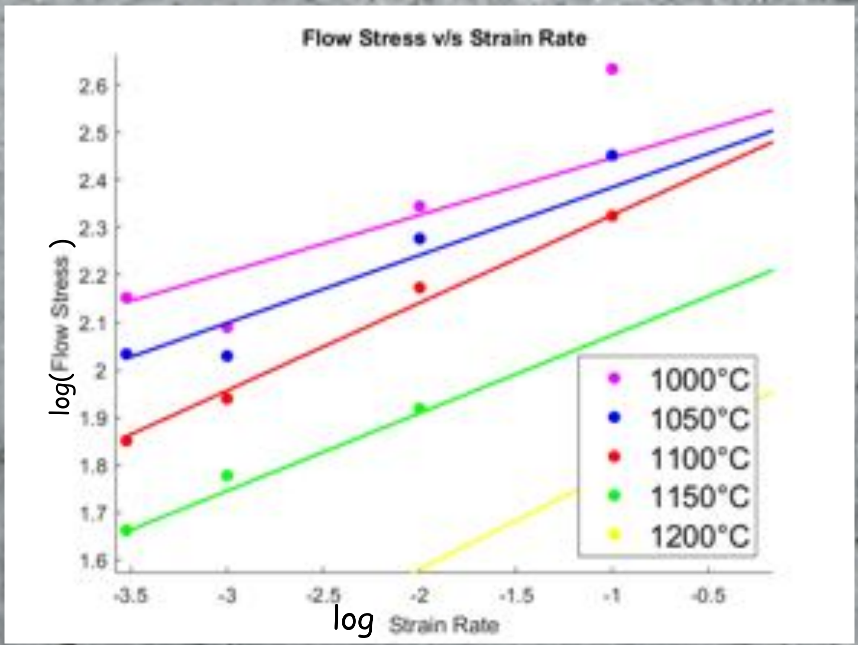
- The microstructure of IN-100 has about 60% (cuboidal) and carbide particles mainly at grain boundaries and to some extent in the matrix.

- Microstructure and chemical analysis results showed that γ' phase was embedded within γ-Ni matrix while various carbides (MC, M23C6 and M6C) were observed as precipitates at grain boundaries or within grains

- IN-100 is a Y-Y' superalloy with a high volume content of Y'.

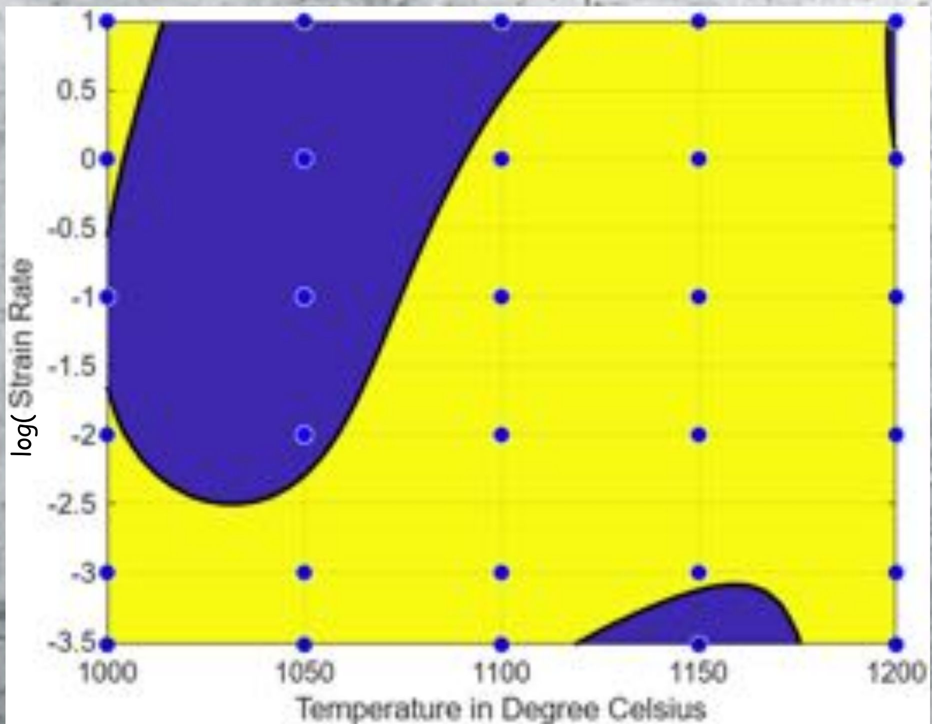
FLOW STRESS VS STRAIN RATE GRAPH IN 100

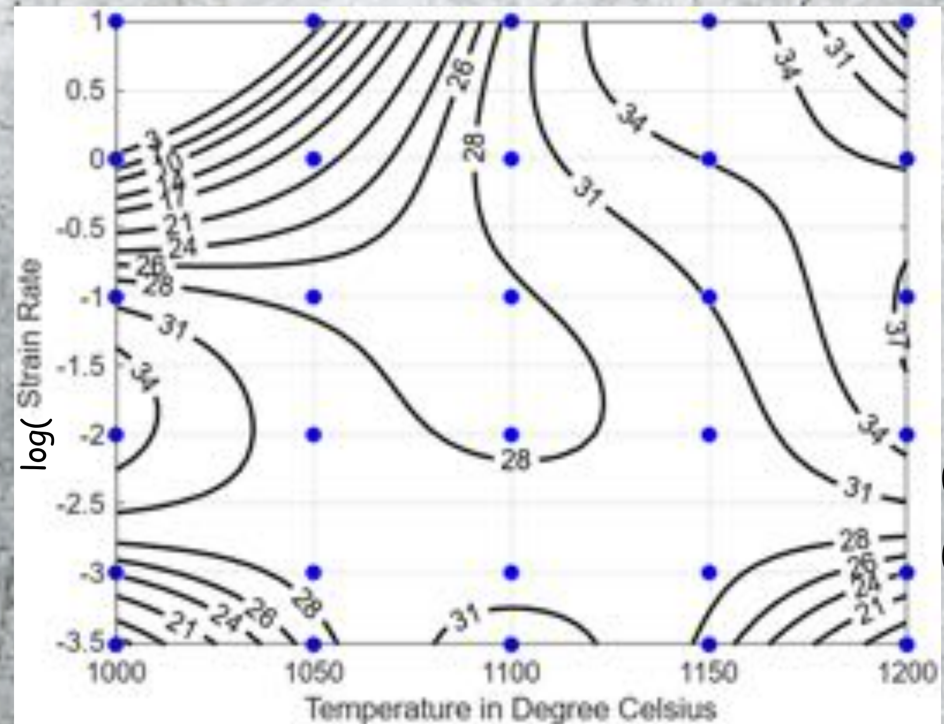
	Strain	Strain Rate	T1	T2	T3	T4	T5
1	NaN	NaN	1000	1050	1100	1150	1200
2	0.3000	0.0003	142	108	71	46	21
3	NaN	0.0010	123	107	87	60	21
4	NaN	0.0100	221	189	149	83	37
5	NaN	0.1000	430	283	211	93	62
6	NaN	1	360	335	337	188	100
7	NaN	10	397	427	472	265	154



$$\sigma = c(\dot{\varepsilon})^m$$

IN-100





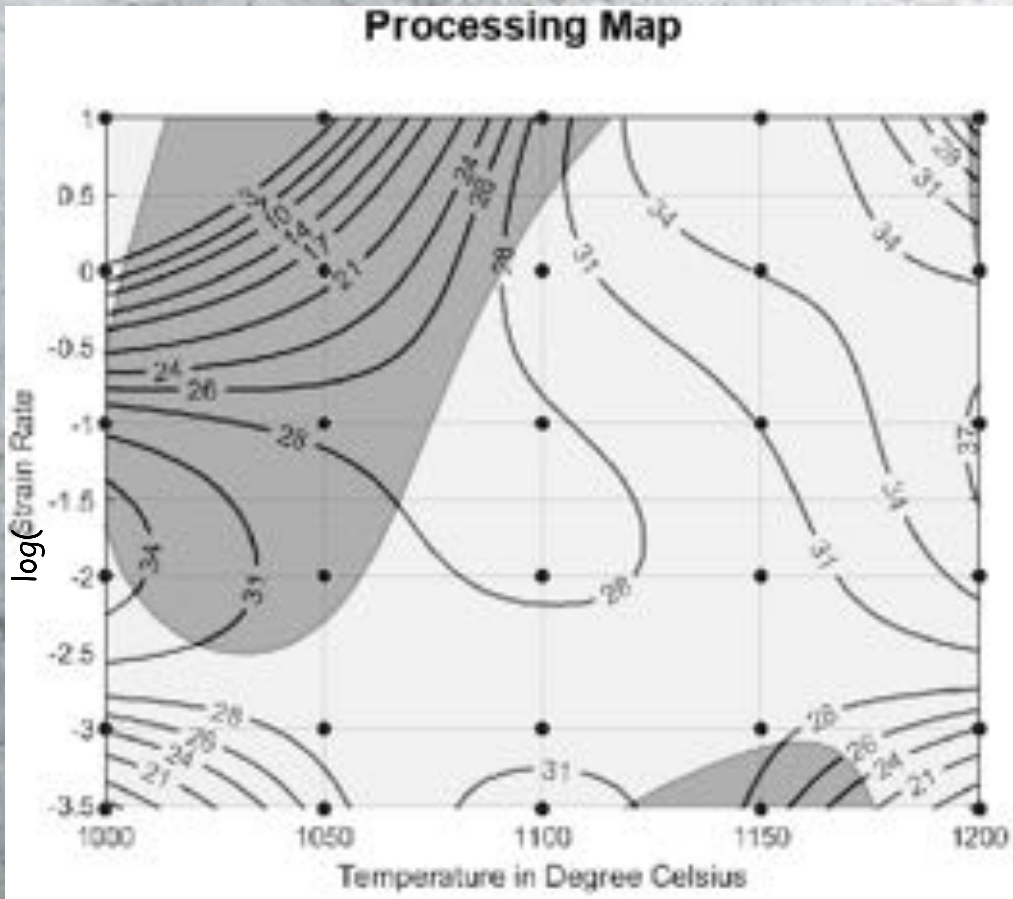
INSTABILITY MAP

POWER DISSIPATION MAP

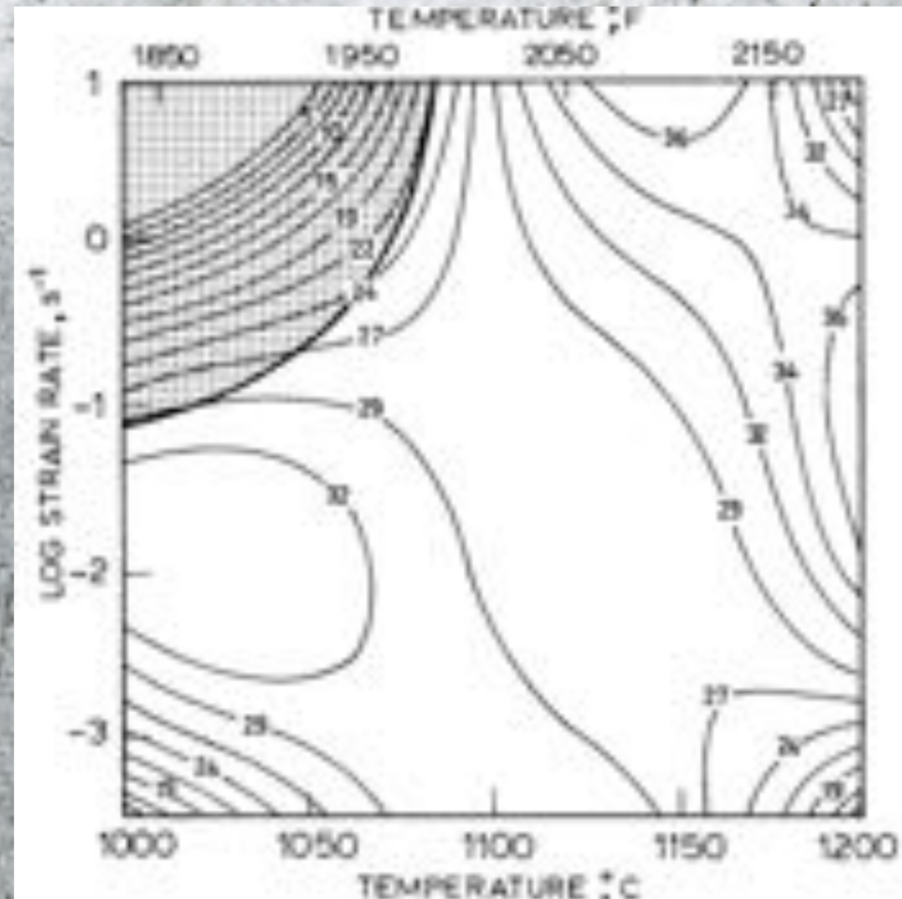
Efficiency of power dissipation

$$\eta = \frac{J}{J_{\max}} = \frac{2m}{m+1}$$

PROCESSING MAPS (IN 100)



0.3 strain rate



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POLYNOMIAL USED : poly41

PROCESSING MAPS (IN 100)

The processing map exhibits three domains: (1) A domain occurring at 1050°Cand 0.01 s-1 with a peak efficiency of about 32%, representing dynamic recovery of y phase.

(2) A domain occurring at 1200oC and 0.01 s-1 with a peak efficiency of about 36% represents DRX of y phase.

log(

(3) A domain occurring at 1150°C and 10 s-1 with a peak efficiency of 36% where DRX of gamma occurs in presence of y' and chunky y'. At temperatures below 1080°C and strain rates higher than 0.1 s-1, the material exhibits
instability in flow which is manifested as intense adiabatic shear bands.

IN-625

- **Material:**

Nickel-Base Superalloy IN625 (PM)

- **Composition: Ni – 62.5, Cr – 19.9, Mo – 9.2, Nb – 3.81, Fe – 2.99, Al – 0.2, Ti – 0.16, Co – 0.10, C – 0.02, Mn –0.05, S – 0.002**

- **Prior History:**

Argon atomized powder was HIP ’ed, and the billet extruded through a rectangular die

MICROSTRUCTURE

- INCONEL alloy 625 is a solid-solution matrix stiffened face-centered-cubic alloy.

- In its microstructure, several phases present include Ni_3Nb (δ), Laves phases and carbides such as MC, M_6C and $M_{23}C_6$

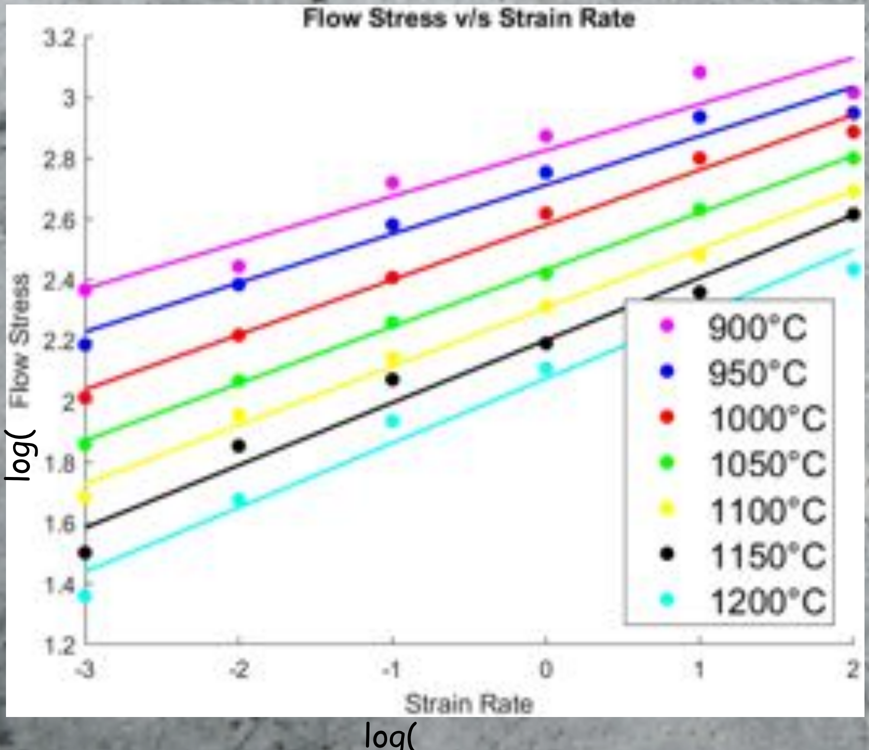
- When heated above 1050°C, all the phases except carbides go into solution

-

- It derives its strength primarily by solid solution strengthening of nickel by Mo, Nb, and Fe.

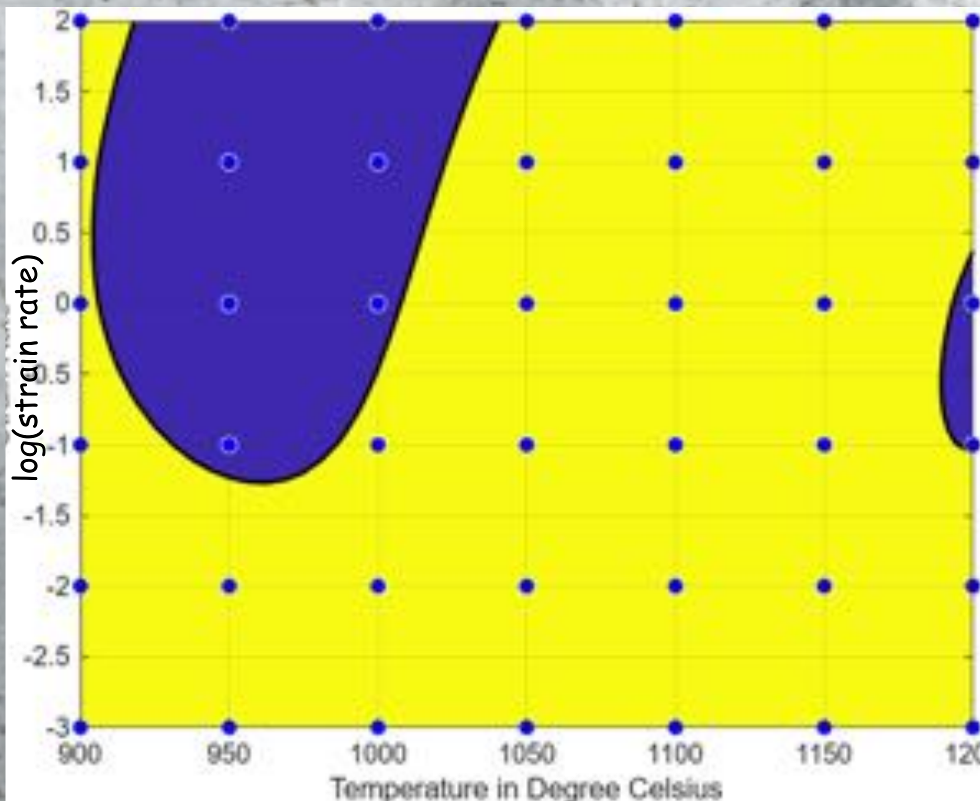
IN-625

	Strain	Strain Rate	T1	T2	T3	T4	T5	T6	T7
1	NaN	NaN	900	950	1000	1050	1100	1150	1200
2	0.5000	0.0010	233	153.9000	103.1000	72.4000	48.7000	31.8000	22.9000
3	NaN	0.0100	278.7000	242.8000	165.5000	117.1000	90.4000	71.4000	47.6000
4	NaN	0.1000	525.6000	382.1000	256.1000	182	139.4000	118.2000	86.2000
5	NaN	1	748.9000	568.4000	416.2000	264.3000	205.2000	155.5000	128.5000
6	NaN	10	1.2144e+03	865.4000	633.3000	429	302.9000	229	200.7000
7	NaN	100	1.0403e+03	891.1000	772.7000	633.1000	492.7000	413.2000	272.4000

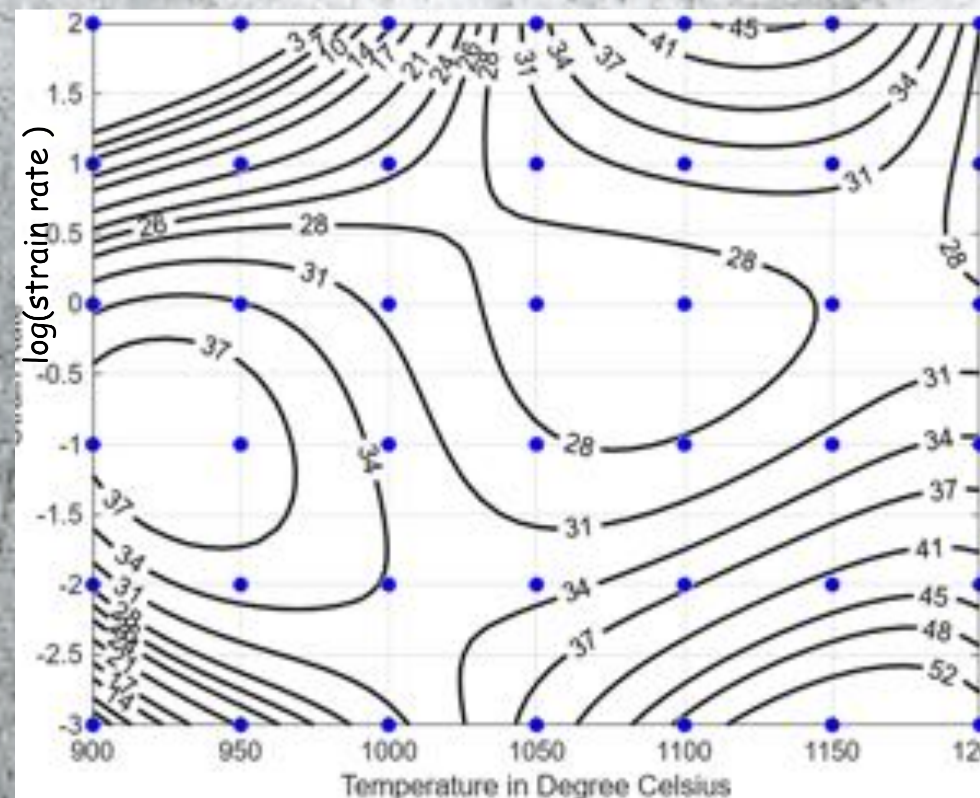


FLOW STRESS VS STRAIN RATE GRAPH

IN-625

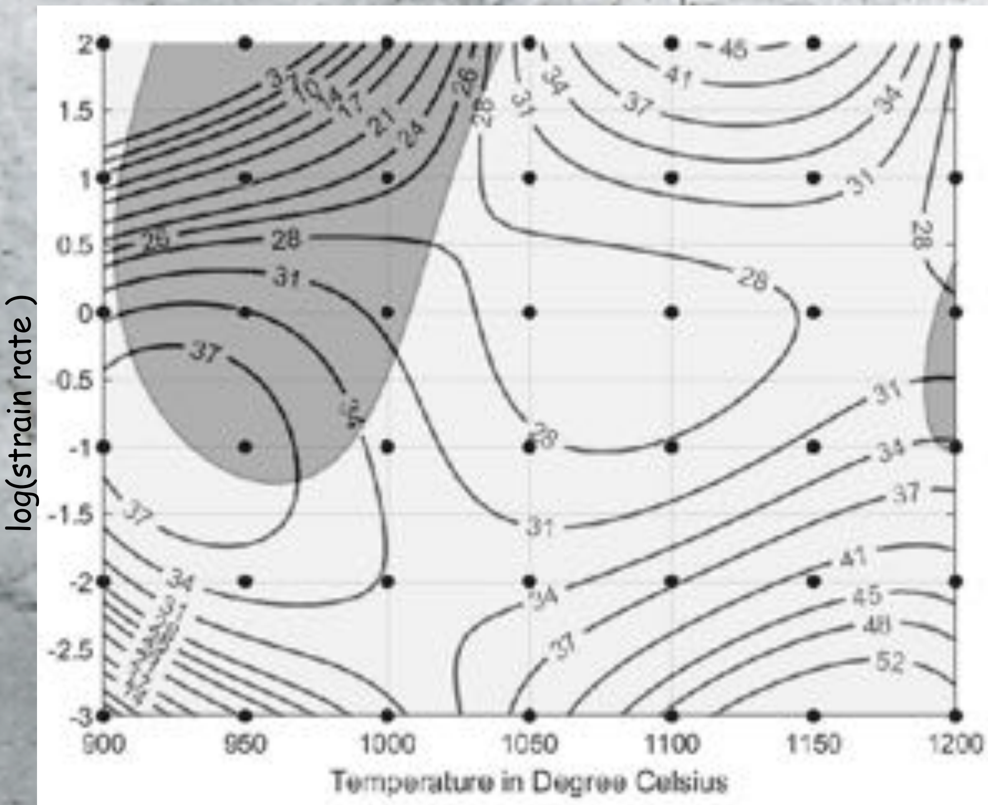


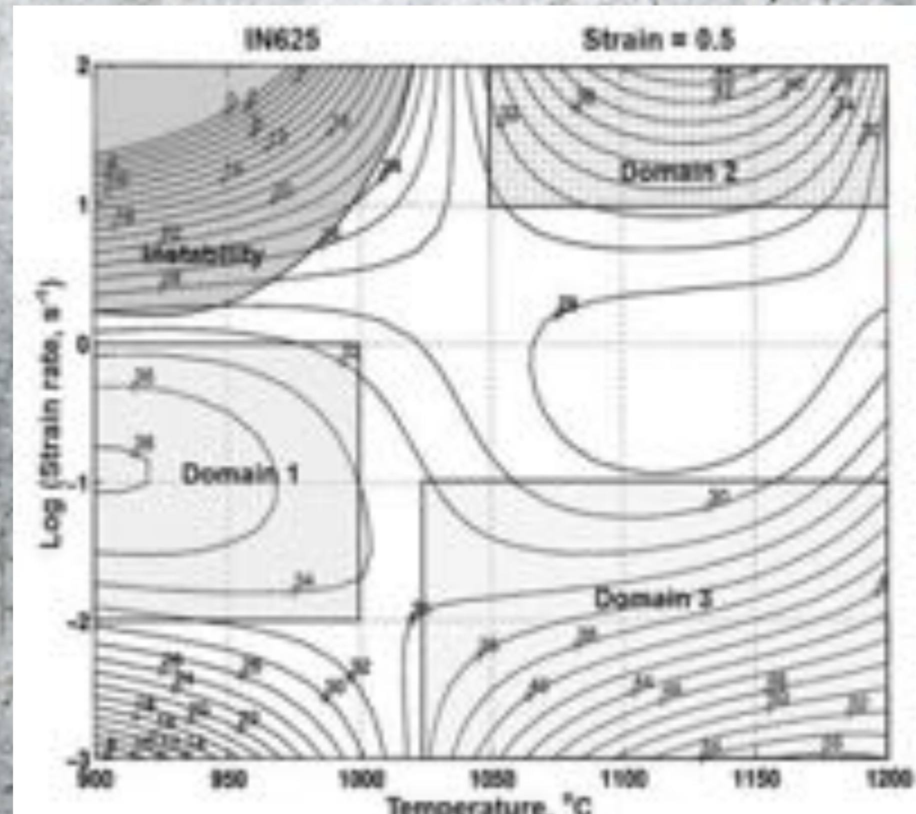
INSTABILITY MAP



POWER DISSIPATION MAP

PROCESSING MAPS IN 625





0.5 strain rate

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POLYNOMIAL USED : poly44

PROCESSING MAPS IN 625

: The map shown here exhibits three domains in the temperature and strain rate ranges given as follows:

(1) 900 – 1000°C and 0.01 – 1.0 s-1 with a peak efficiency of 38% occurring at 900°C/0.1-1, representing DRX of γ phase occurring in the presence of precipitates and carbide particles. (2) 1050 – 1200°C and 10 – 100 s-1with a peak efficiency of 44% at 1125°C and 100 s-1, representing DRX of γ phase after the precipitate dissolution.

The material exhibits flow instability in the temperature range 900 – 1025°C and at strain rates higher than 1.0 s-1 manifesting as adiabatic shear bands.

IN-600

- **Material: IN-600**
- **Composition: Cr-16.5, Fe-7.85, C-0.02, Mn-0.8, Si-0.34, Cu-0.05, S-0.0005, Ni- bal.**
- **Prior History: Hot rolled and annealed. Average grain diameter: 50um**

IN-600

- IN-600 is a high temperature nickel alloy used in aerospace and nuclear applications.

- The addition of Fe improves the workability of Ni-Cr alloys and enhances the service temperature.

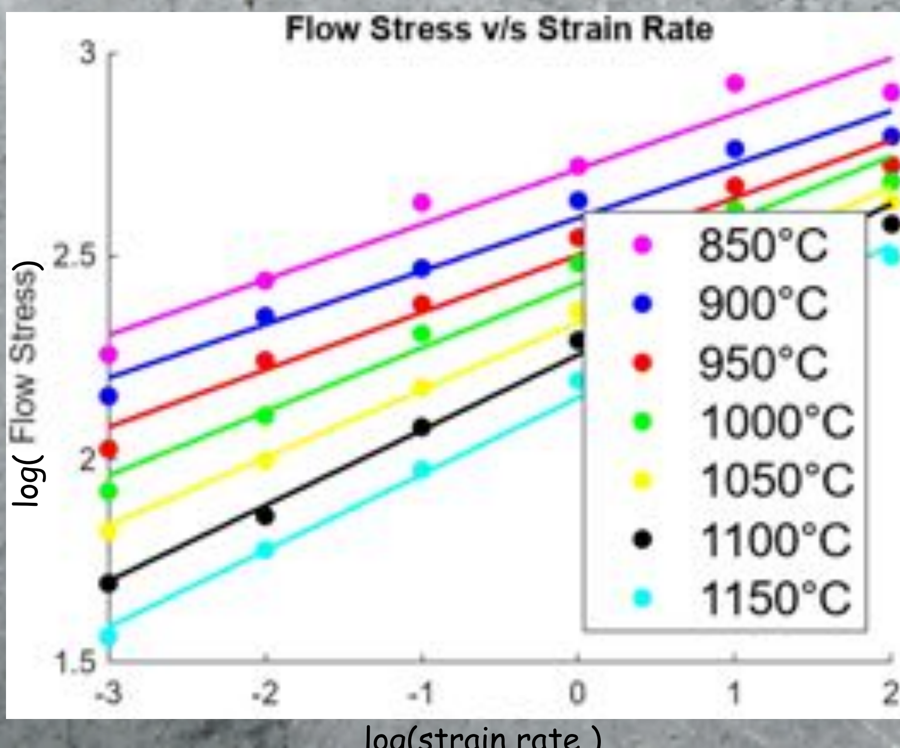
- The hot workability of IN-600 is better at temperatures higher than 1000°C and the hot ductility exhibits a minimum at 700°C.

- The hot workability reaches high values at 1150-1250°C. The presence of Fe reduces the activation energy for diffusion of chromium in nickel, resulting in an increase in diffusivity.

IN-600

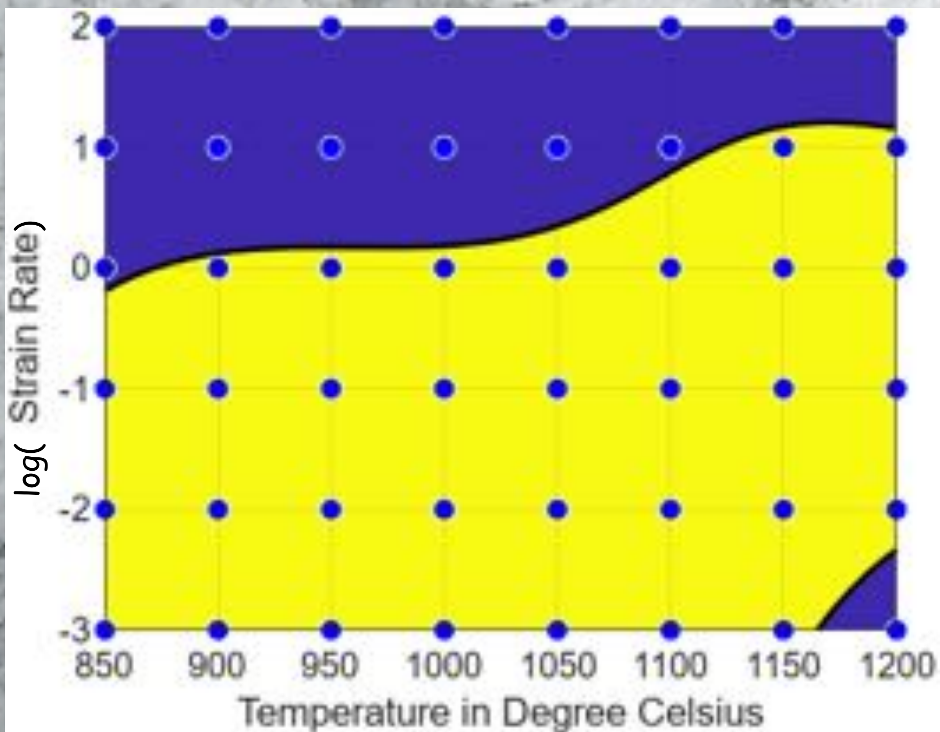
	Strain	Strain Rate	T1	T2	T3	T4	T5	T6	T7	T8
1	NaN	NaN	850	900	950	1000	1050	1100	1150	1200
2	0.5000	0.0010	181	143	106	83.4000	66.6000	49.5000	36.6000	28.5000
3	NaN	0.0100	275	225	175	128	99.4000	72.5000	59.8000	26.1000
4	NaN	0.1000	428	295	241	204	150	120	94.2000	47.6000
5	NaN	1	526	433	351	303	232	196	156	124
6	NaN	10	841	580	470	411	336	303	217	181
7	NaN	100	799	623	529	482	430	379	316	246

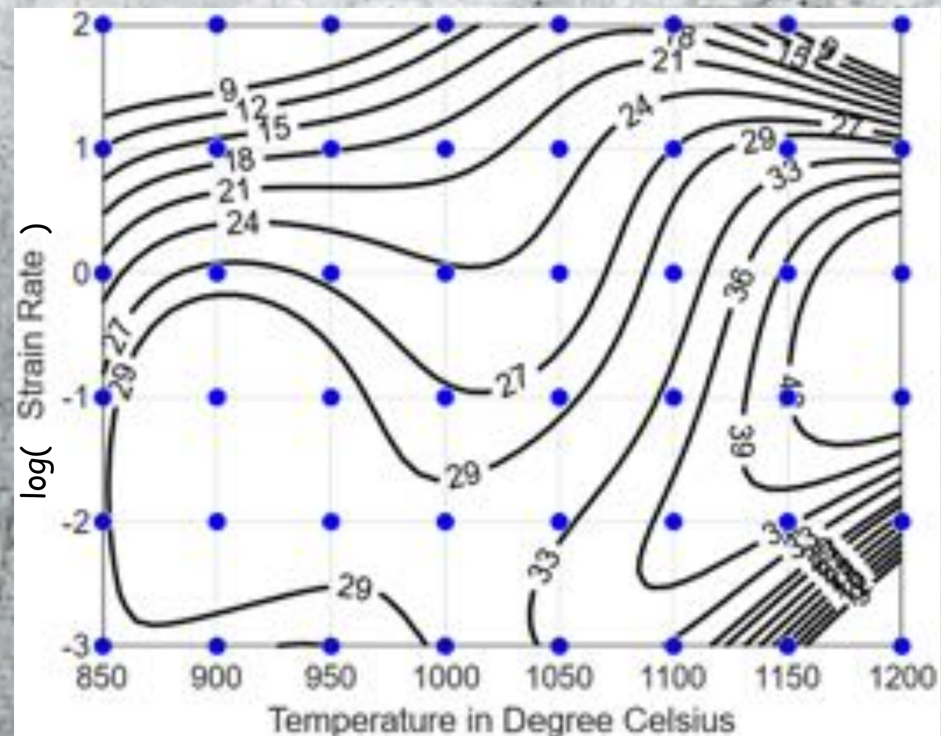
Processing map for IN625 at a strain of 0.5. The region of flow instability is superimposed as hatched area.



FLOW STRESS VS STRAIN RATE GRAPH

IN-600

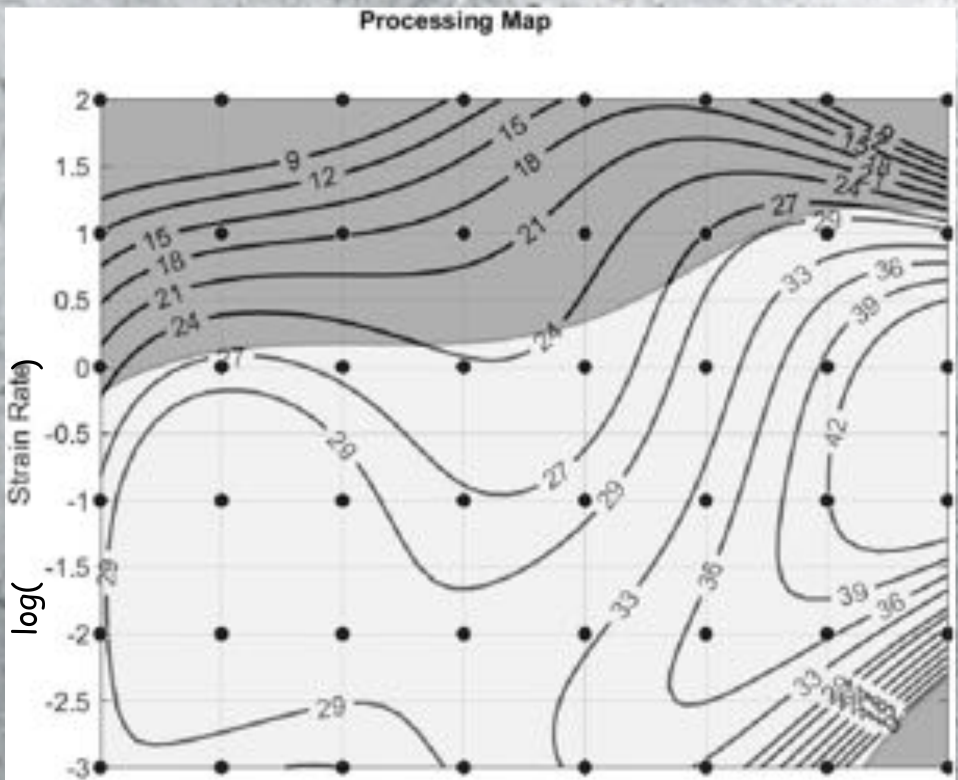


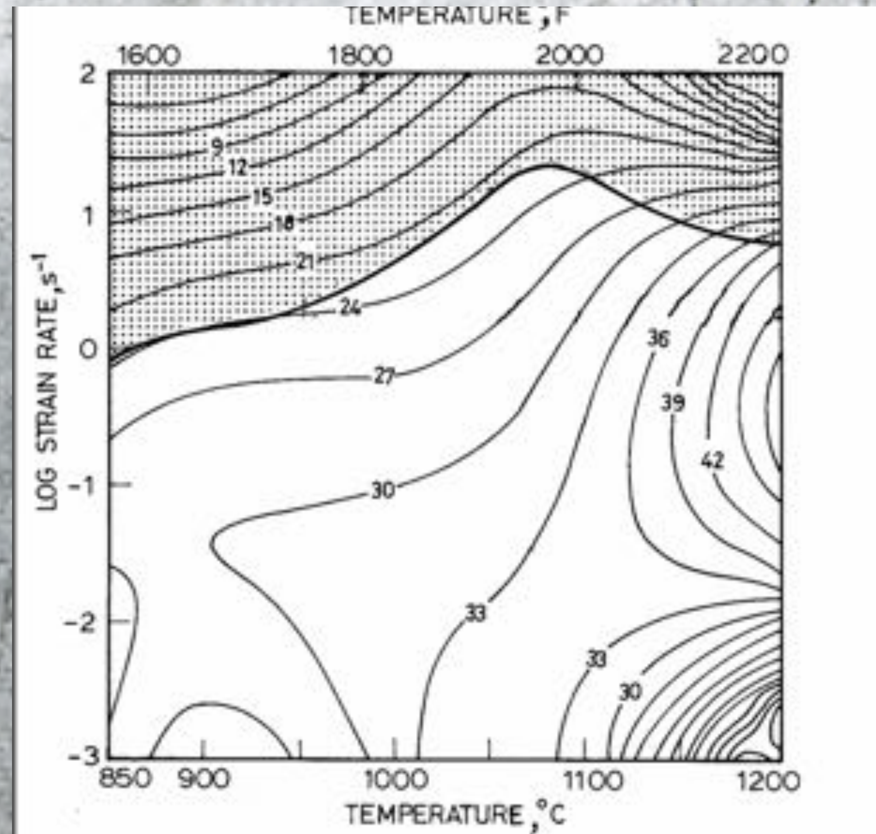


INSTABILITY MAP

POWER DISSIPATION MAP

IN-600





0.5 strain rate

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POLYNOMIAL USED : poly45

PROCESSING MAP OF IN-600

- The map exhibits two domains: (1) A domain occurring at 1100-1200°Cand strain rates in the range 0.01 to 1 s-1 with a peak efficiency of 48% occurring at 1200°C and 0.2s-1, represents dynamic recrystallization (DRX) process. (2) A domain occurring at 900°C and 0.001 s-1 with an efficiency of 27% represents dynamic recovery. The carbide dissolution occurs over temperature range of 950-1100°C and DRX domain occurs only after the dissolution of carbides.
- At lower temperatures, the microstructure has statically recrystallized grains formed after dynamic recovery and resembles ‘necklace’ structure
- The material exhibits flow instability at all temperatures in the range tested and at strain rates higher than 1 s-1.
- At 1200°C and 0.001 s-1, the material exhibits extensive grain growth.

IN-718

- **Material: IN-718**
- **Composition: Hot Rolled**
- **Prior History: As-cast alloy (vacuum arc refined) was homogenized at 1190°C for 24 hours and water quenched.**

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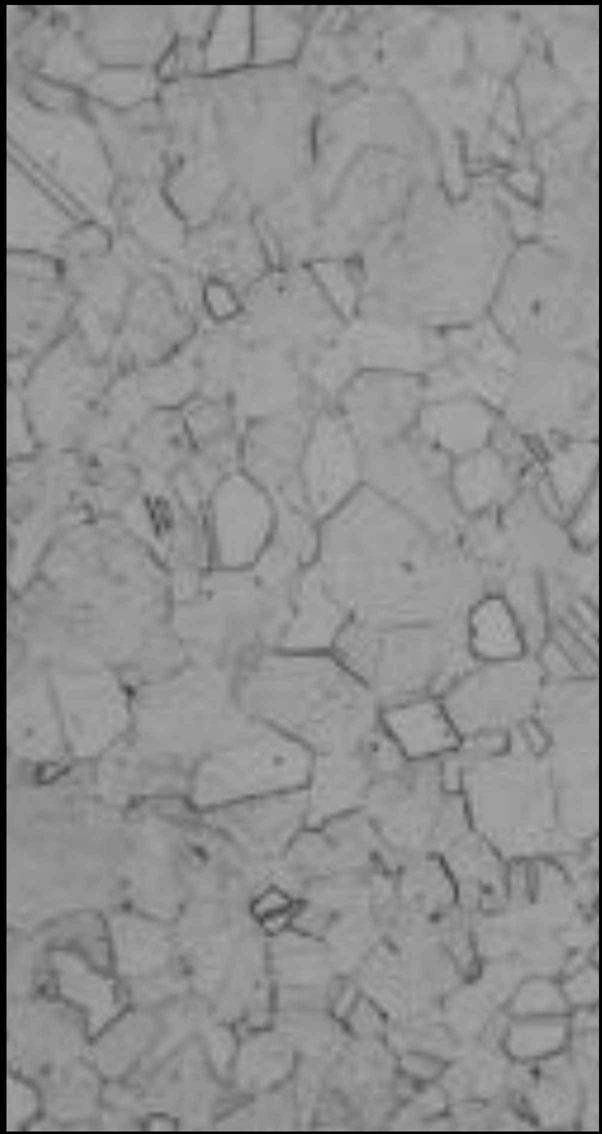
MICROSTRUCTURE



IN-718

- The microstructure of Inconel 718 constitutes γ solid supersaturated solution matrix rich in Ni, Cr and Fe with precipitates of coherent phases of γ″ (Ni_3Nb) and γ′ $Ni_3(Al,Ti)$.

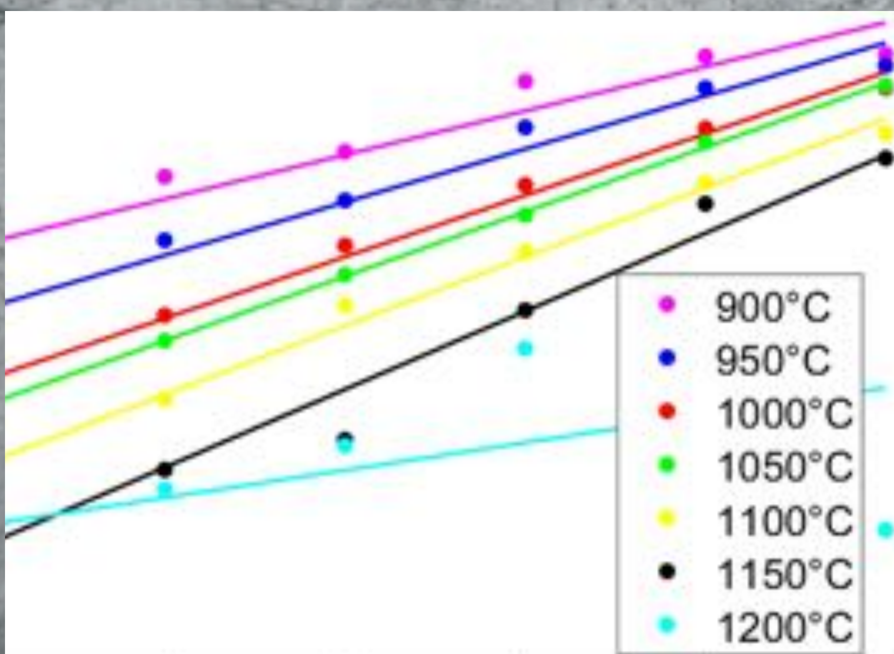
- The coherent γ′ and γ″ phases form a morphology that realizes the microstructure stability of the alloy if proper reaction takes place during precipitation.

- Nb is one of the age hardening constituents of Inconel 718 which is highly susceptible to segregation and tend to form some undesirable phases, including NbC, δ-Ni_3Nb and the Laves phases, known for degrading tensile ductility, fatigue and creep rapture properties

IN-718

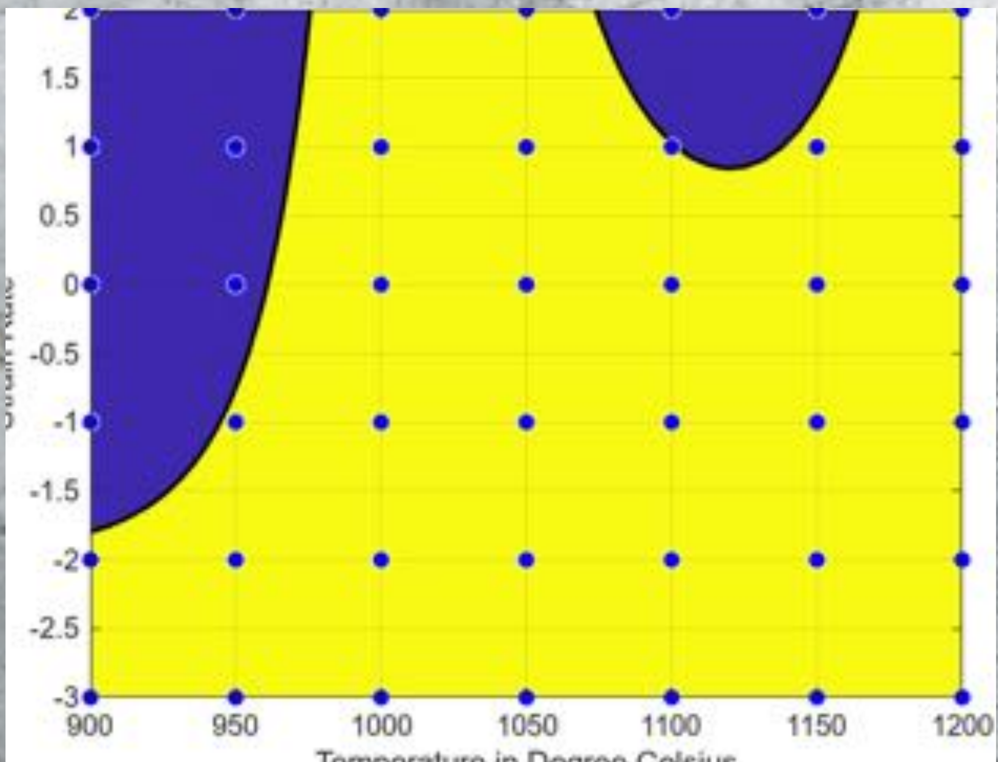
	Strain	Strain Rate	T1	T2	T3	T4	T5	T6	T7
1	NaN	NaN	900	950	1000	1050	1100	1150	1200
2	0.5000	0.0010	164	119	82.6000	77.3000	51.5000	39.8000	24.5000
3	NaN	0.0100	294	203	131	113	80.4000	53.3000	47.6000
4	NaN	0.1000	340	256	197	166	139	63.4000	61.3000
5	NaN	1	512	392	280	235	190	135	108
6	NaN	10	593	493	390	359	284	251	126

Processing map for IN-718 at a strain of 0.5. The region of flow instability is superimposed as hatched area.

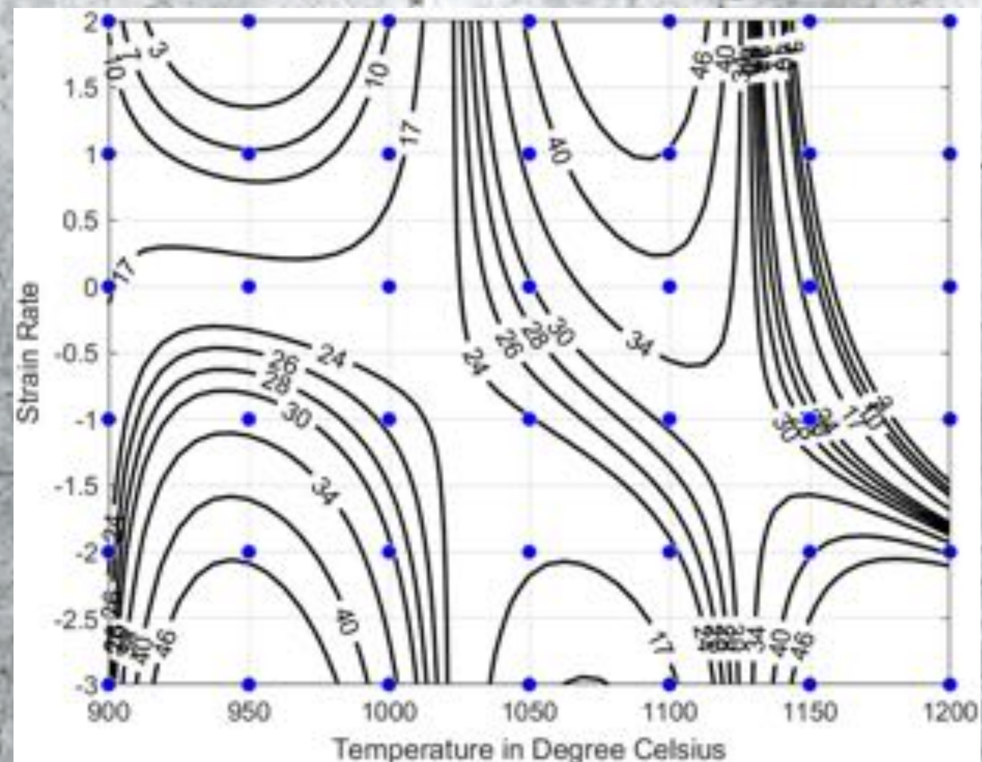


FLOW STRESS VS STRAIN RATE GRAPH

IN-718

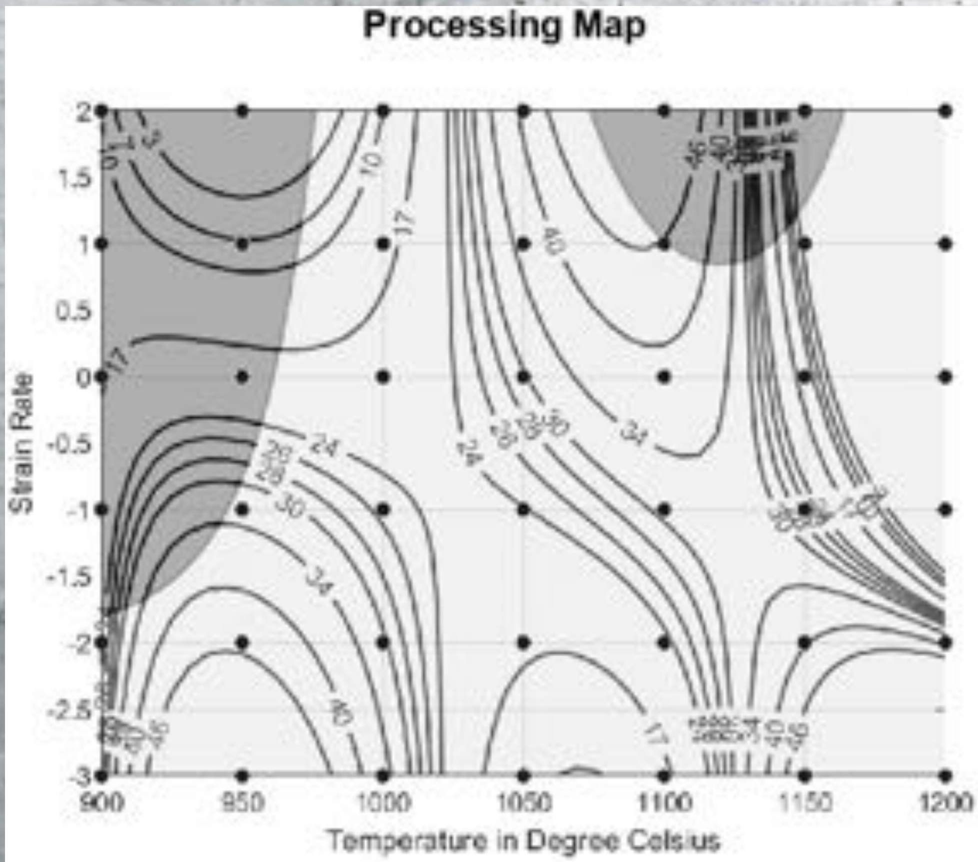


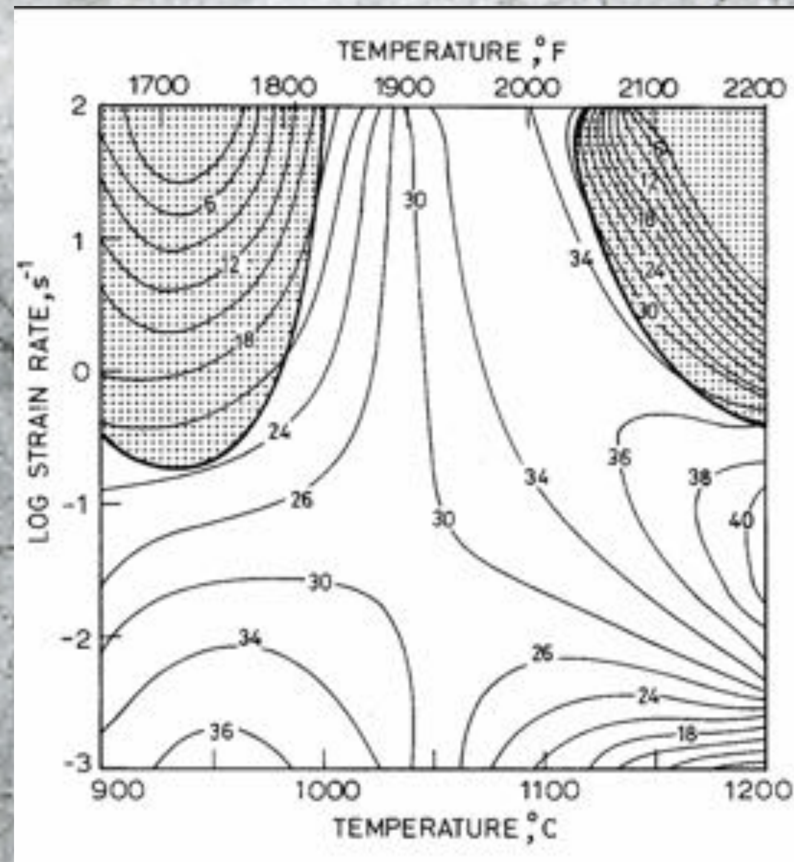
INSTABILITY MAP



POWER DISSIPATION MAP

IN-718





0.5 strain rate **Book**

POLYNOMIAL USED : poly41

REFERENCES:

- https://en.wikipedia.org/wiki/Dynamic_recrystallization
- https://www.sciencedirect.com/topics/engineering/dynamic-recrystallization
- (PDF) Factors affecting dynamic recrystallization of metals and alloys (researchgate.net)
- https://www.sciencedirect.com/topics/engineering/processing-map
- Hot Working Guide—A Compendium of Processing Maps, Second Edition Y.V.R.K. Prasad, K.P. Rao, and S. Sasidhara, editors

THANK

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