THE APPLICATION OF THERMODYNAMICS IN LOW PLASTICITY BURNISHING

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OUTLINE

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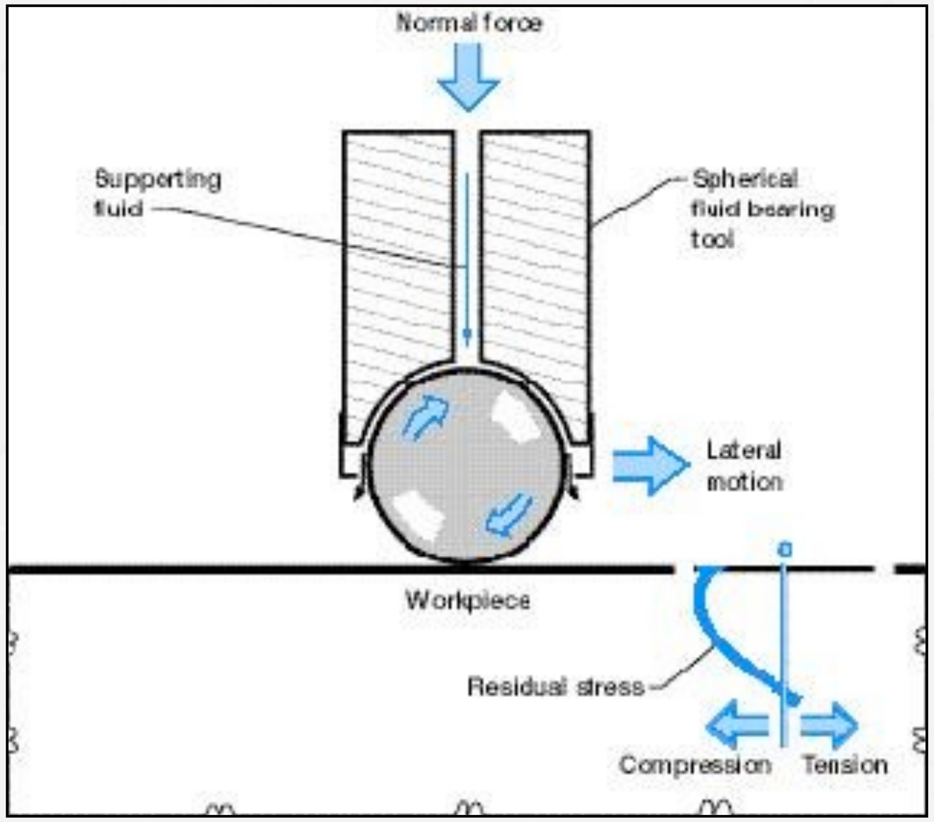
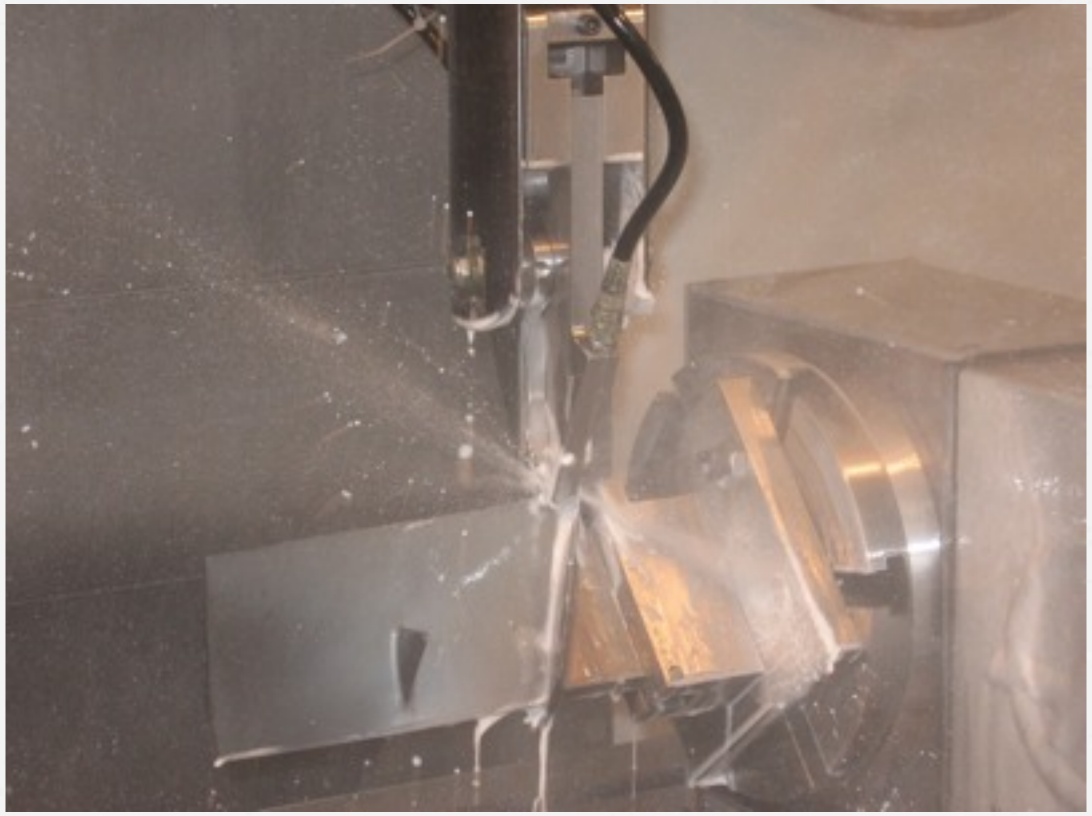
- Related Thermodynamics knowledges
- Conclusions

LOW PLASTICITY BURNISHING





LPB™ uses a patented constant volume hydrostatic tool design to "float" the burnishing ball continuously during operation, regardless of the force applied.

LOW PLASTICITY BURNISHING

- Low Plasticity Burnishing (LPB™) uses the minimal amount of plastic deformation (or "cold working") needed to create the level of residual stress to improve fatigue or stress corrosion performance. Low cold working provides both thermal and mechanical stability of the beneficial compression.

RESIDUAL STRESS

RESIDUAL STRESSES are a consequence of interactions among time, temperature, deformation and microstructure (Fig. 1).

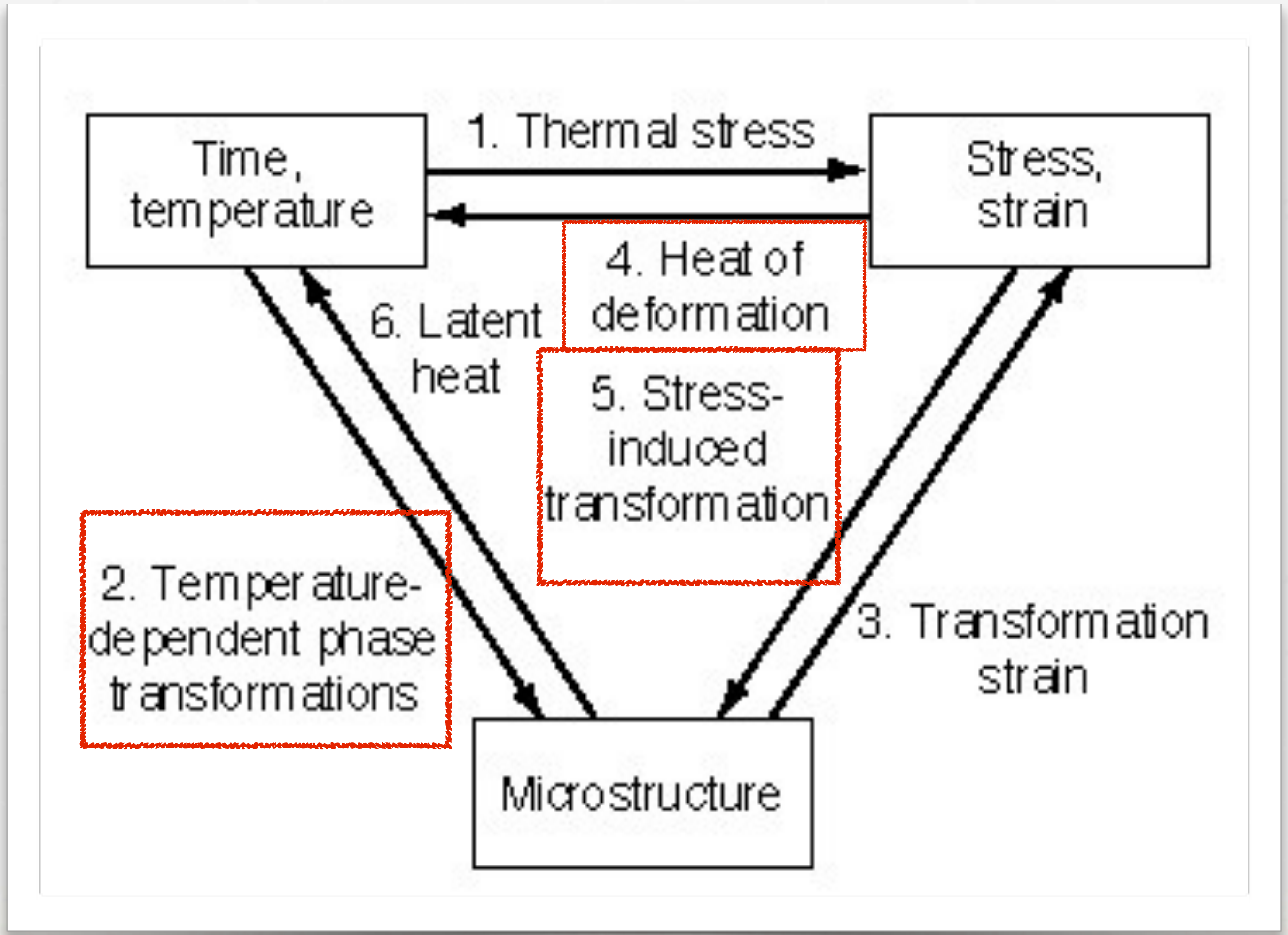


Figure1. The coupling of temperature, stress, and microstructure.

Handbook of Residual Stress and Deformation of Steel

RELATED THERMODYNAMICS

- 1. Temperature Rise During Deformation.
- 2. Transformation Induced Plasticity.

TEMPERATURE RISE DURING DEFORMATION

- The temperature of the metal rises during plastic deformation, because of the heat generated by mechanical work. [1]
- Adiabatic temperature rise occured during the fast deformation, if the deformation is adiabatic (no heat transfer to the surroundings) the temperature rise can be calculated as following .[4]

TEMPERATURE RISE IN LPB

1.Calculate the area of the ball indentation on the surface of sample under load.

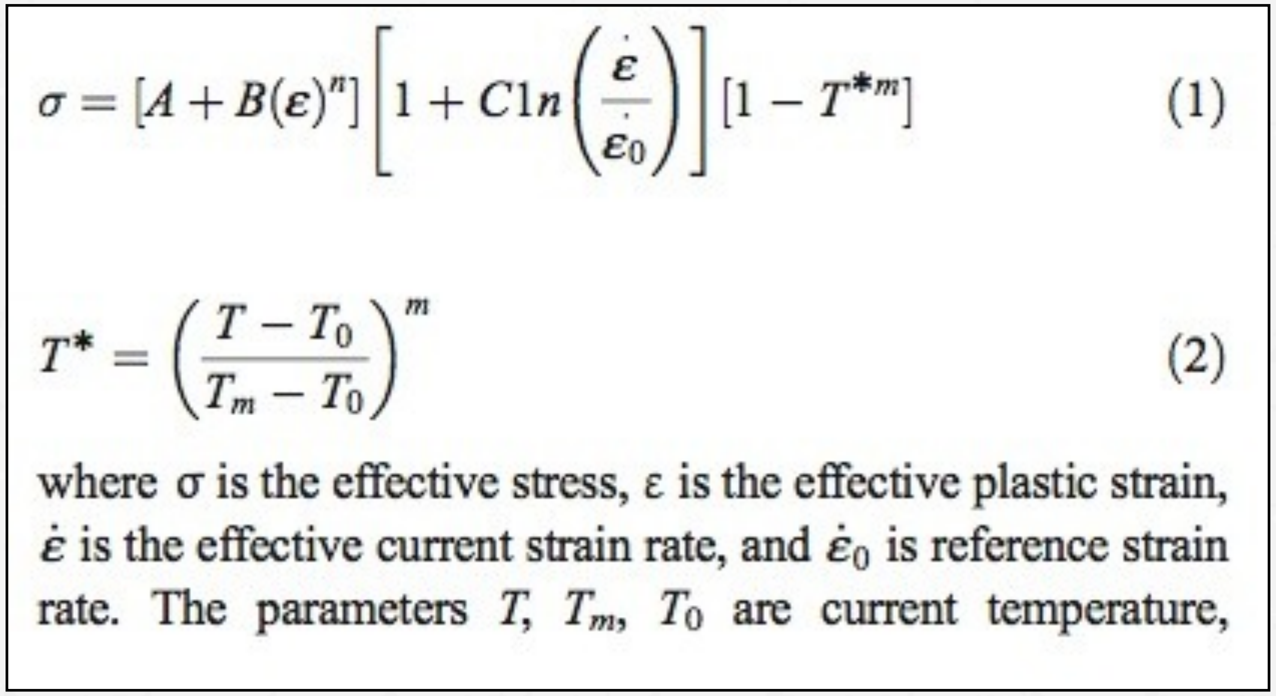
$$\sigma_{\text{ball}} = \frac{2P}{\pi D(D - \sqrt{(D^2 - d^2)})}$$

where:
P = applied force (kgf)
D = diameter of indenter (mm)
d = diameter of indentation (mm)

In LPB process,a hydraulic pressure of 200bar(≈20MPa) is planning to be used,and the diameter of the ball is 6mm.

TEMPERATURE RISE IN LPB

2.The flow stress has been modeled by the J-C strength model :

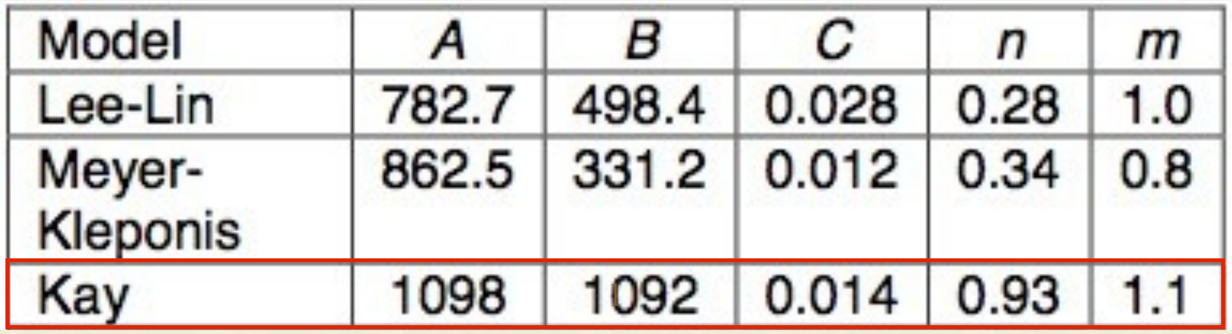


$$\sigma = [A + B(\varepsilon)^n]\left[1 + C\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right][1 - T^{*m}] \qquad (1)$$

$$T^* = \left(\frac{T - T_0}{T_m - T_0}\right)^m \qquad (2)$$

where σ is the effective stress, ε is the effective plastic strain, $\dot{\varepsilon}$ is the effective current strain rate, and $\dot{\varepsilon}_0$ is reference strain rate. The parameters T, T_m, T_0 are current temperature,

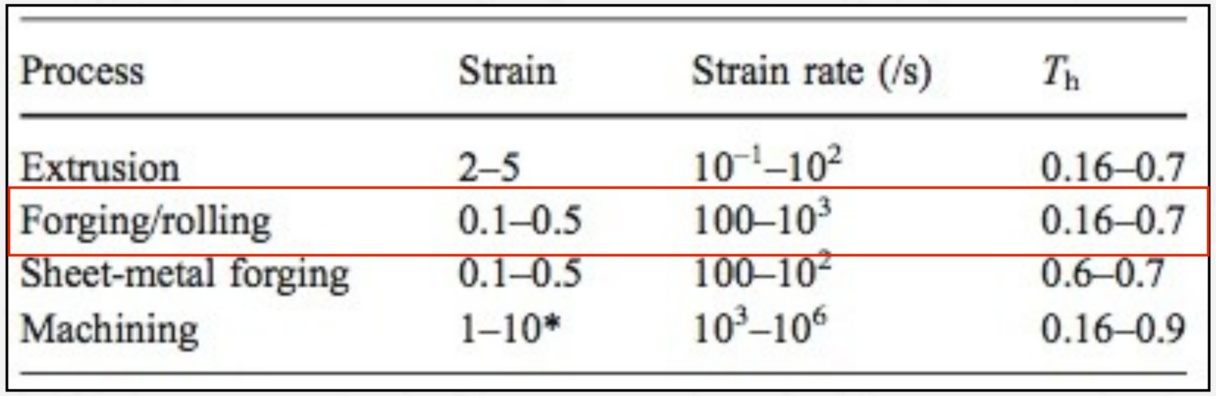
TABLE 1: CONSTANTS OF J-C MODEL FOR TI-6AL-4V.[7]



Model	*A*	*B*	*C*	*n*	*m*
Lee-Lin	782.7	498.4	0.028	0.28	1.0
Meyer-Kleponis	862.5	331.2	0.012	0.34	0.8
Kay	1098	1092	0.014	0.93	1.1

TEMPERATURE RISE IN LPB

Table 2 Typical strains, strain rates, and temperatures (Th=T/Tmelt) of some manufacturing processes[7]



Process	Strain	Strain rate (/s)	T_h
Extrusion	2–5	10^{-1}–10^{2}	0.16–0.7
Forging/rolling	0.1–0.5	100–10^{3}	0.16–0.7
Sheet-metal forging	0.1–0.5	100–10^{2}	0.6–0.7
Machining	1–10*	10^{3}–10^{6}	0.16–0.9

σ can be known after step 1. Put all the need values shown in Table 1 and Table 2 into equation (1), gets the risen temperature after Low Plasticity Burnishing :

→ $T=511°C$

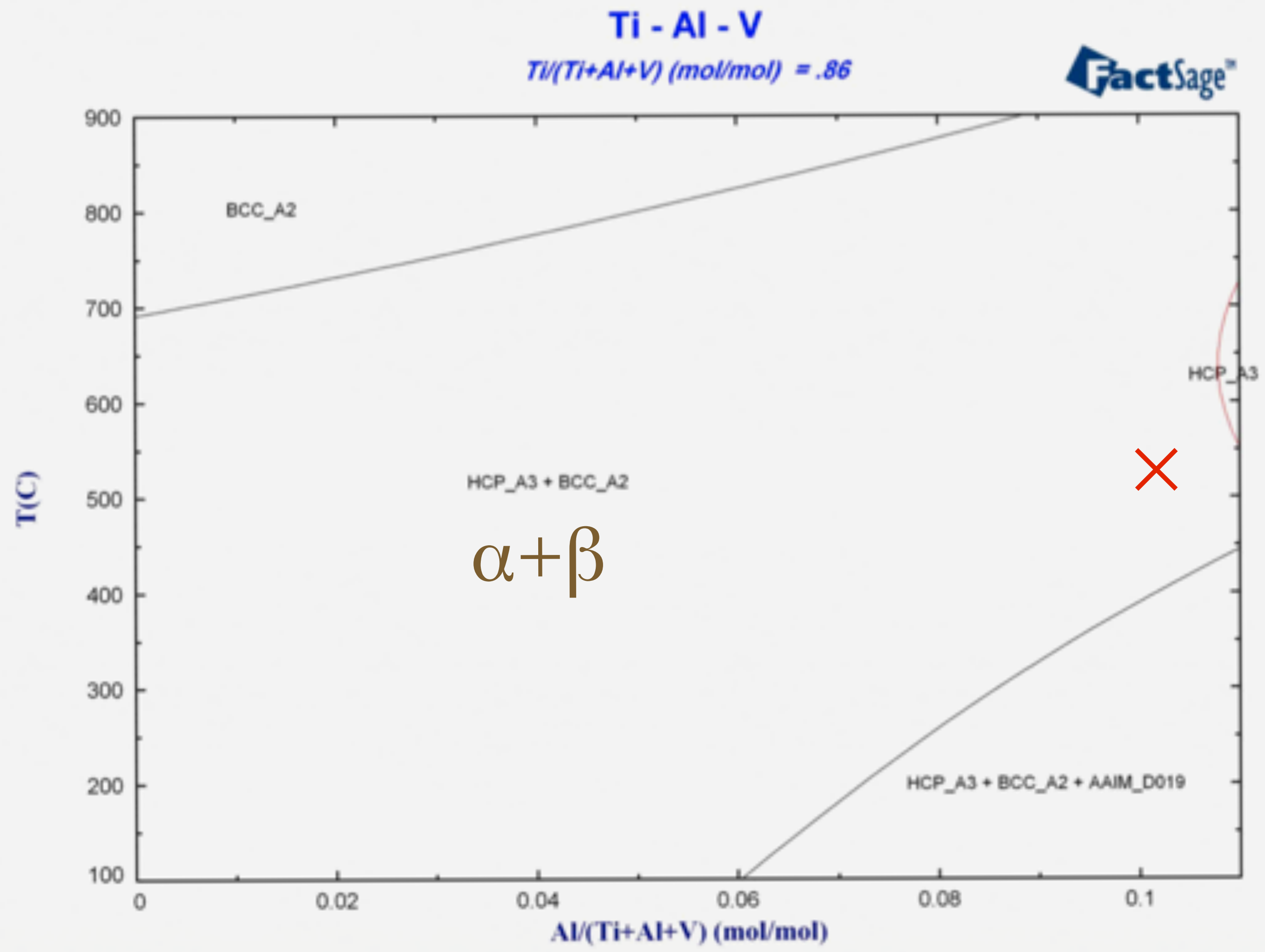
TI6AL4V PHASE DIAGRAM

With temperature risen to 511°C due to deformation occured in LPB process, the microstructure of the surface would be affected. The details could be shown in the Ti6AL4V phase diagram as followed:

Table 3 Components percentage og Ti6Al4V

Component	Wt.%	Atomatic%
Ti	90	86
Al	6	10
V	4	4

TI6AL4V PHASE DIAGRAM



TRANSFORMATION DURING DEFORMATION

- Deformation plays the leading role in changing the properties of the surface layer.
- The understanding of the evolution of microstructures subjected to plastic deformation is also extremely important, especially for alloys used in metal forming processes.

TITANIUM PHASE RELATIONS

- Two different crystal structures of pure titanium: a low temperature HCP alpha(α) phase, and a high-temperature BCC beta (β) phase. The transition between these phases occurs at 882℃, termed the β-transus temperature. This temperature can be modified by alloy composition, which can be used to engineer combinations of α and β titanium phases tailored to desired microstructures.[5]

TITANIUM ALLOYS

- **Alpha alloys:** high resistance to fracture, as well as fatigue. They also tend to be easier to weld than other titanium alloys, and are highly resistant to corrosion.
- **Beta alloys:** can achieve higher strengths than alpha alloys, but are also less tough.
- It is characterized as a rich a+β alloy in which particular Al&V balance provides attractive mechanical properties.[6]

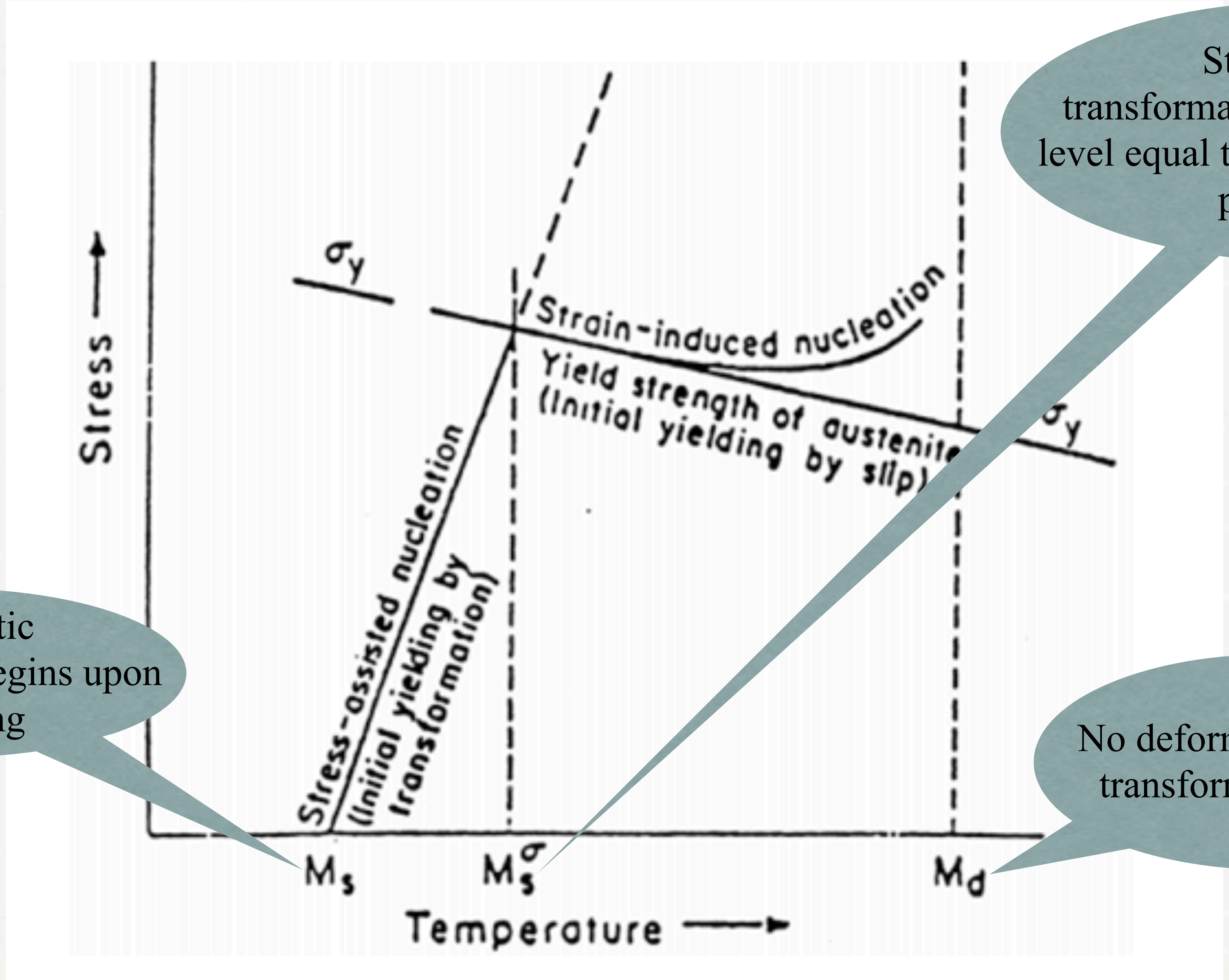
TRANSFORMATION INDUCED PLASTICITY

- **The "TRIP" effect**: The transformation induced plasticity phenomenon occurs when the retained austenite transforms to martensite during plastic deformation.[2]
- Transformation Induced Plasticity (TRIP) steels exhibit an excellent combination of mechanical properties due to the transformation of austenite to martensite and the complex interaction between the various phases under load.[3]

MARTENSITIC TRANSFORMATION IN TITANIUM ALLOYS

- The concept of transformation-induced plasticity may be extended to titanium alloys,exploiting martensitic transformation of the β parent phase. Alloy strength and corrosion resistance is provided by grain refinement and the solid solution strengthening of the α phase. Toughness is increased by optimized martensitic transformation of the β phase during deformation. [5]

MARTENSITIC TRANSFORMATION IN TITANIUM ALLOYS



Stress-assisted transformation occurs at a stress level equal to the yield stress of the parent phase

Martensitic transformation begins upon cooling

No deformation-induced transformation occurs

Figure 5: Stress and temperature relations for stress-assisted and strain-induced martensitic transformations [5]

MARTENSITIC TRANSFORMATION IN TITANIUM ALLOYS

- The driving force for transformation of the parent β phase to martensite is composed of mechanical and chemical components. [5]

$$\Delta G_{tot} = \Delta G_{chem} + \Delta G_{mech}$$

Here ΔGtot is the total free energy change of the martensitic transformation, ΔGchem is the chemical free energy difference between parent and martensite phases at a given temperature in units J/mol. ΔGchem values are computed by ThermoCalc using the licensed Thermotech Ti-DATA-v3 thermodynamic database. ΔGmech is given by the following equation:

$$\Delta G_{mech} = -\left(0.7 * 0.7183\bar{\sigma} + 6.85\frac{\Delta V}{V}\sigma_h - 185.3\left(1 - e^{-0.003043\bar{\sigma}}\right)\right)$$

CONCLUSIONS

- The temperature could be risen up to725°C during Low Plasticity Burnishing,but using sufficient coolant during the whole process could reduce the value.
- After being LPB treated,the surface microstruture of Ti6AL4V samples should be composed of α+β phases. Combination of both alpha(α) phase and beta (β) phase would be beneficial to the improvement of water erosion resistance.

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THANKS