# The analysis of different damage accumulation models for simulation of hot and warm working of $\alpha+\beta$ titanium alloys

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**OPTIMoM 2014**

# Damages in the finished parts and during manufacturing

*The majority of research works is concentrated on the fracture analysis and strength prediction of the parts during their exploitation.*

*In this analysis the material of the parts is assumed to be in some "ideal initial state".*

How can we estimate
the performance of critical parts
like these carabiners
in case of loading?

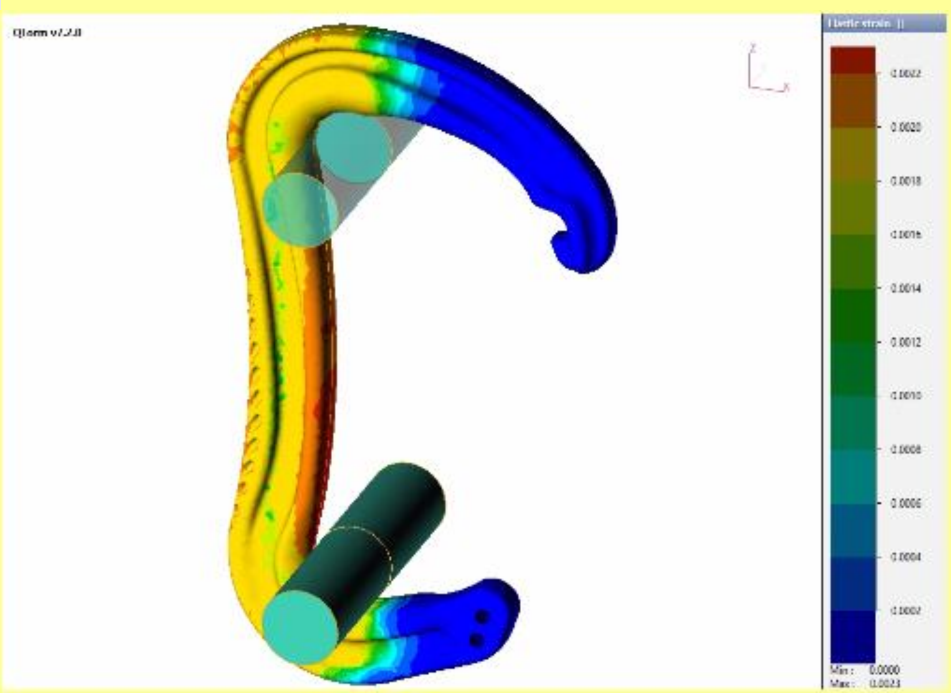
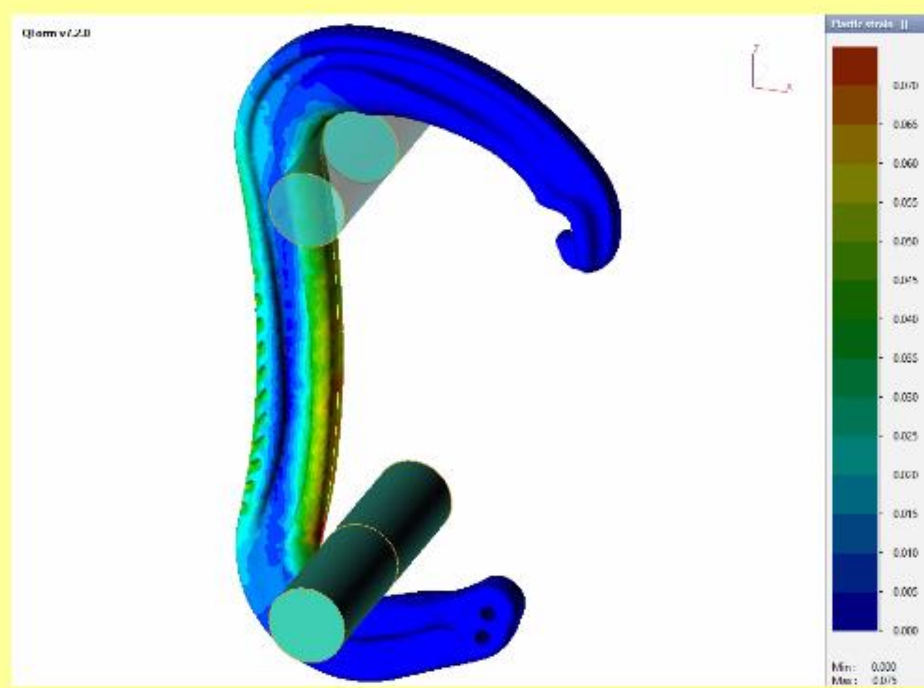
Courtesy of DMM, Llanberis, Wales

QForm UK

# Simulation of climbing carabiner pull test: elastic-plastic material model

**In his test we usually presume that the material has uniform and known properties.**

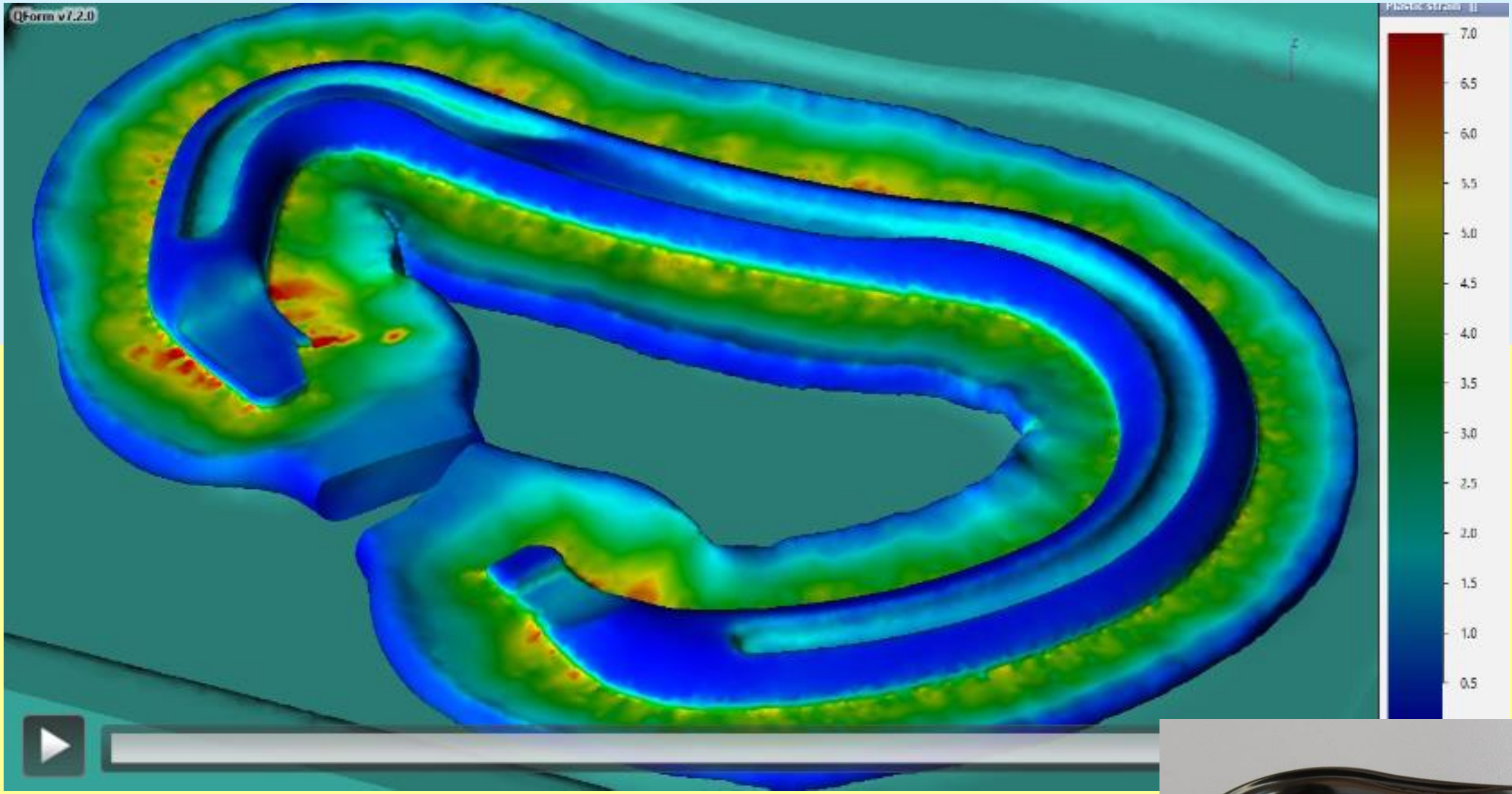
Courtesy of DMM, Llanberis, Wales, QForm 7 simulation

| Elastic component of strain | Plastic component of strain |
|---|---|
|  |  |

QForm UK

# Forging of carabiners. Strain distribution in simulation

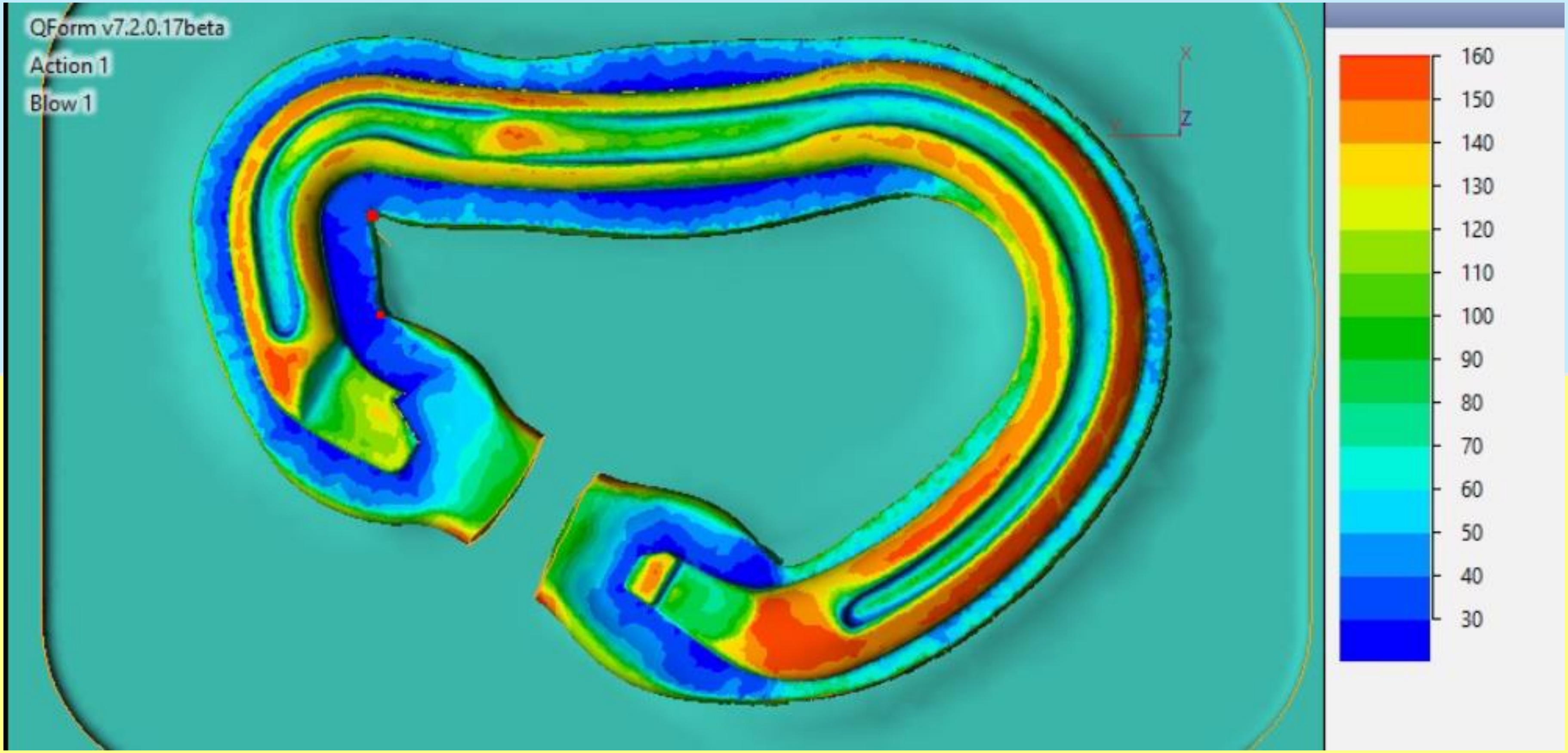
**Meanwhile during manufacturing different parts of the product subject to different deformation**




Courtesy of DMM, Llanberis, Wales, QForm 7 simulation

QForm UK

**Because deformation is performed in hot state different parts of the product have different grain size and texture that also influence the product performance**




**Forging of carabiners. Grain size distribution prediction (mkm)**

Courtesy of DMM, Llanberis, Wales,
QForm 7 simulation

## Damages in the finished parts and during manufacturing

*The damage accumulation  starts from the very beginning of the manufacturing process.*

*In less lucky cases the fracture may happen during forming of the part.*

*The parts even without evident cracks and defects have certain accumulated damage like microcracks and pores occurred during forming, machining, welding etc. that cannot be healed by heat treatment.*

## The aim of the work

*To analyze the applicability of different approaches for prediction of fracture and assessment of workability in hot and warm technological metal forming processes*

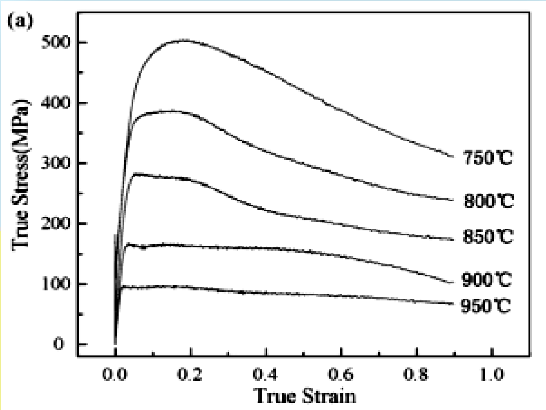
*Find out possibilities of their utilization in FEM simulation*

# The specific features in simulation of technological processes of metal forming

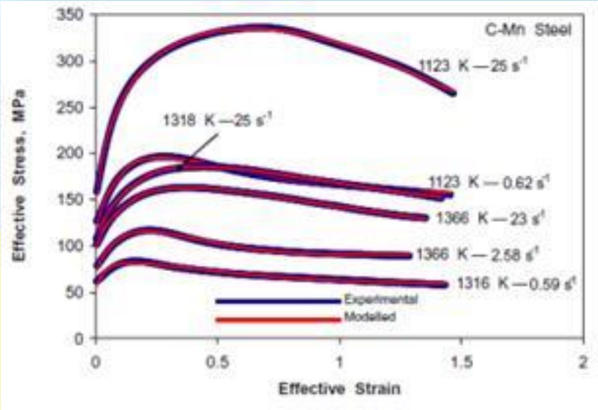
- *Technological process normally consists of several operations*
- *Variable stress state, complex loading trajectories, different ranges of the strain rates can be used at different operations,.*
- *The maximum workability of the material significantly depends on the temperature and strain rate*
- *The microstructure of the material can undergo transformation*
- *Microstructure transformation can result in the softening of the material.*

# Main Requirements to a Fracture – Damage Model

- *To be able to take into account temperature and strain rate sensitivity*
- *To be suitable for the materials with the deformation softening*
- *To be able to assess the remaining resource of workability at the any stage of the chain of technological operations*
- *To be easy and robust calibrated with the standard tests*

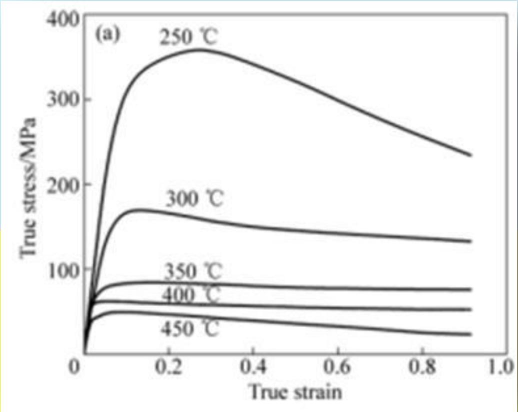


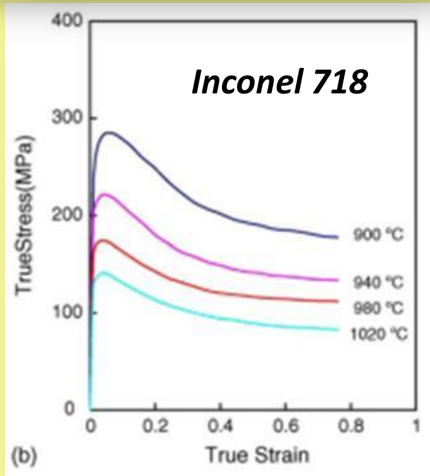

***TC11 titanium alloy***
***(Ti–6.5Al–3.5Mo–1.5Zr–0.3Si)***




***C–Mn steel***

***7075 aluminum alloy***




***Inconel 718***


*Y.Y. Zong, D.B. Shan, M. Xu, Y. Lv Flow softening and microstructural evolution of TC11 titanium alloy during hot deformation Journal of Materials Processing Technology 209 ( 2009 ) 1988–1994*

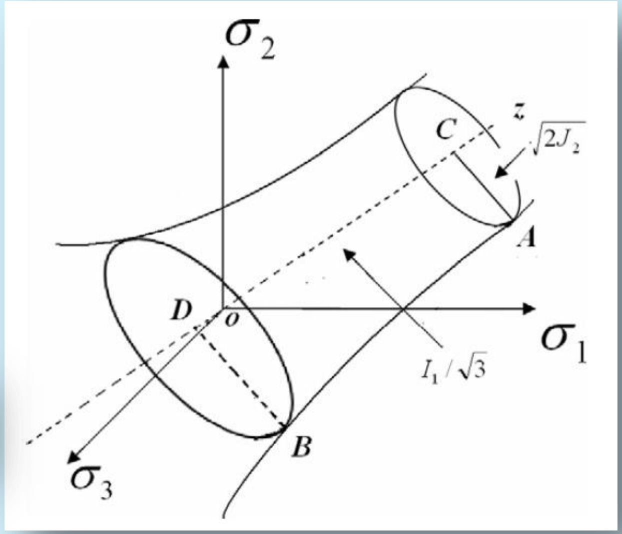
*E.S. Puchi-Cabrera, M.H. Staia, J.D. Guŭrin, J. Lesage, M. Dubar, D. Chicot*
*An experimental analysis and modeling of the work-softening transient due to dynamic recrystallization International Journal of Plasticity 54 (2014) 113–131*

*H. Yuan, W.C. Liu Effect of the $\delta$ phase on the hot deformation behaviour of Inconel 718 Materials Science and Engineering A 408 (2005) 281–289*

*QUAN Guo-zheng, LIU Ke-wei, ZHOU Jie, CHEN Bin Dynamic softening behaviors of 7075 aluminum alloy Trans.Nonferrous Met.Soc.China 19 92009) 537-541*

# Strength based criteria

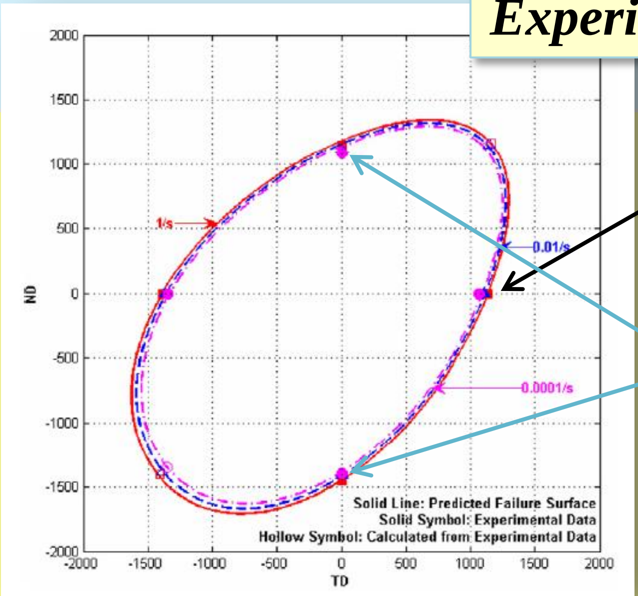
In the space of stresses (full stress tensor, stress deviator or principal stresses) there exist some fracture surface and fracture happens when stress vector reaches it.




$$\sqrt{e^{C(\xi+1)}(F\sigma_1^2+G\sigma_2^2+H\sigma_3^2+L\sigma_1\sigma_2+M\sigma_1\sigma_3+N\sigma_2\sigma_3)} = e^{c_1 I_1/\sqrt{3}}\dot{\varepsilon}^n T^{*m}$$

Model Akhtar S. Khan, Haowen Liu, 2012

***Experiments used for surface construction***




Uniaxial:

tension

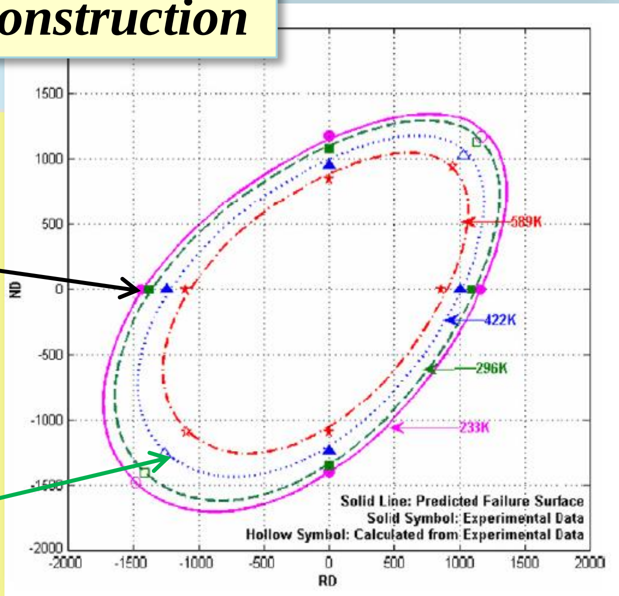
compression

Plane:

torsion

Triaxial:

Compression + hydrostatic pressure





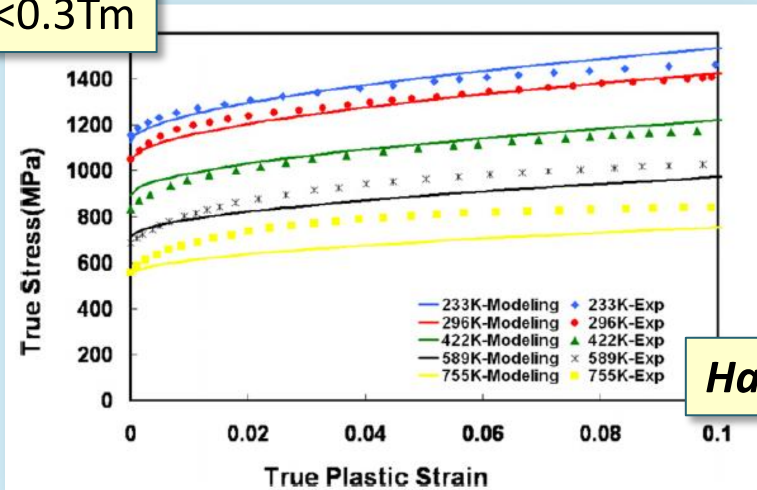
***Khan, A.S., Liu, H., 2012. Strain rate and temperature dependent fracture criteria for isotropic and anisotropic metals. Int. J. Plast. 37, 1-15***

*Khan, A.S., Yu, S., 2012. Deformation Induced anisotropic responses of Ti–6Al–4V alloy. Part I: Experiments. Int. J. Plast. 38 1–13*

*Khan, A.S., Yu, S., Liu, H., 2012. Deformation induced anisotropic responses of Ti–6Al–4V alloy. Part II: Strain rate and temperature dependent anisotropic yield criterion. Int. J. Plast. 38 14–26*

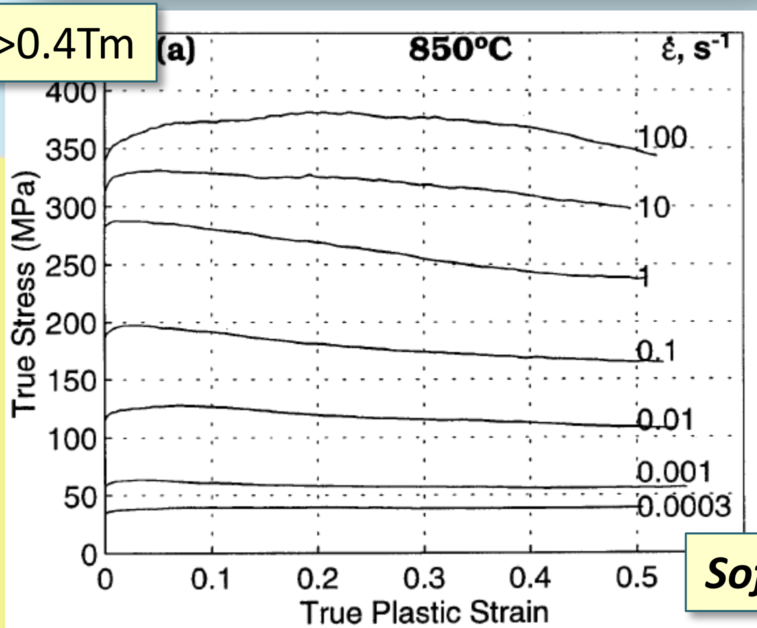
## *The range of applicability…*
## ***Hardening and Softening***
## *e.g.,Ti-6Al-4V*

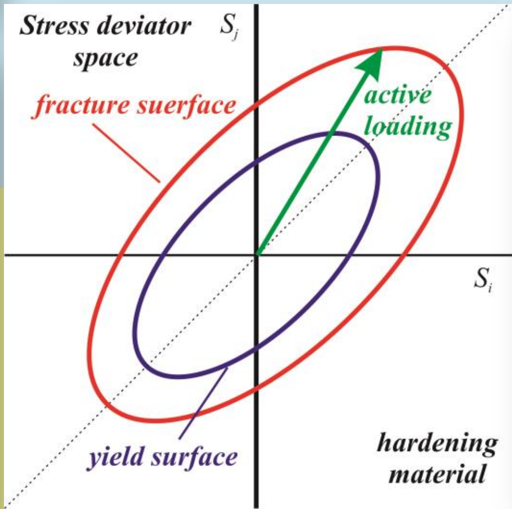
T<0.3Tm

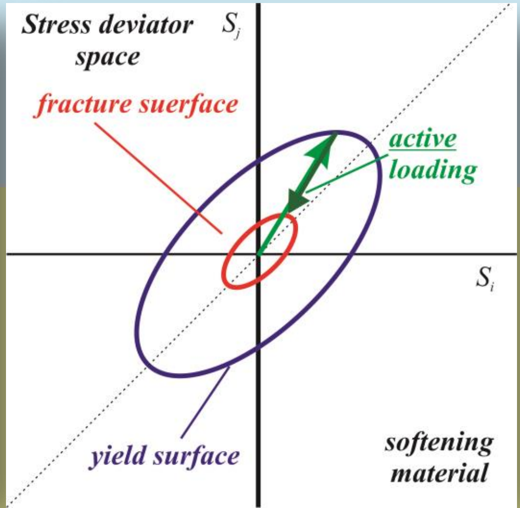



***Hardening – strength-based criteria can be applied***

T>0.4Tm



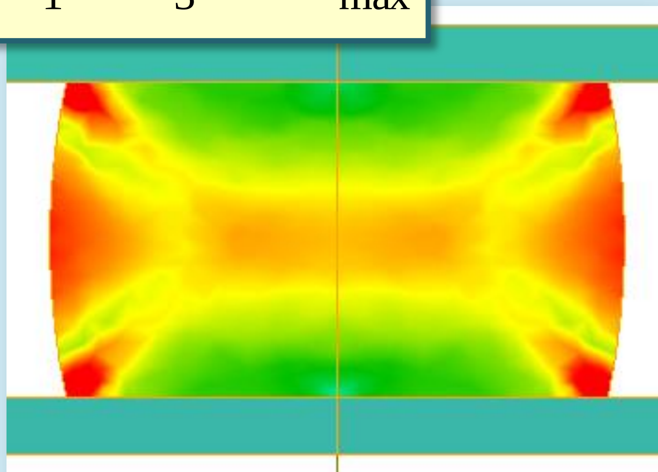




***Softening – strength-based criteria are not applicable***


*Khan, A.S., Liu, H., 2012. Strain rate and temperature dependent fracture criteria for isotropic and anisotropic metals. Int. J. Plast. 37, 1-15*
*Khan, A.S., Yu, S., 2012. Deformation Induced anisotropic responses of Ti–6Al–4V alloy. Part I: Experiments. Int. J. Plast. 38 1–13*
*Khan, A.S., Yu, S., Liu, H., 2012. Deformation induced anisotropic responses of Ti–6Al–4V alloy. Part II: Strain rate and temperature dependent anisotropic yield criterion. Int. J. Plast. 38 14–26*
*Seshacharyulu,T., et al., 2000. Hot working of commercial Ti–6Al–4V with an equiaxed $\alpha$-$\beta$ microstructure: materials modeling considerations. Materials Science and Engineering A284 184–194*

## *Hardening materials:*
## *Maximum Shear Stress Theory*

$$\sigma_1 - \sigma_3 \le 2\tau_{max}$$



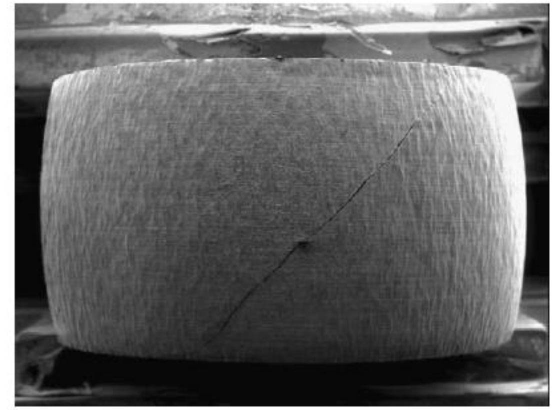


Fig. 2. Shear fracture in an upsetting test of 2024-T351 A1.

## *Softening materials: ???????*

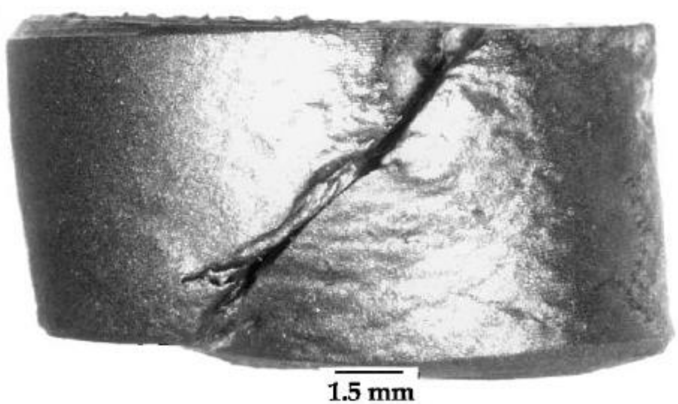
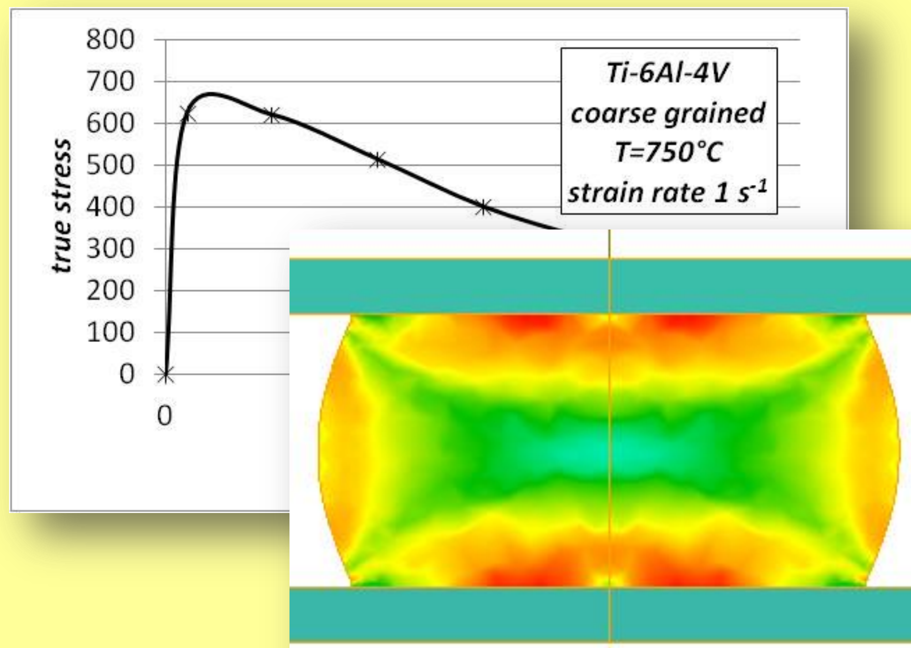



Fig. 4. Macro picture of Ti–6Al–4V specimen deformed at 750 °C/ 10 s$^{-1}$ exhibiting cracking. The compression axis is vertical.



# Deformation based criteria

***Constant Equivalent Strain (ES)***

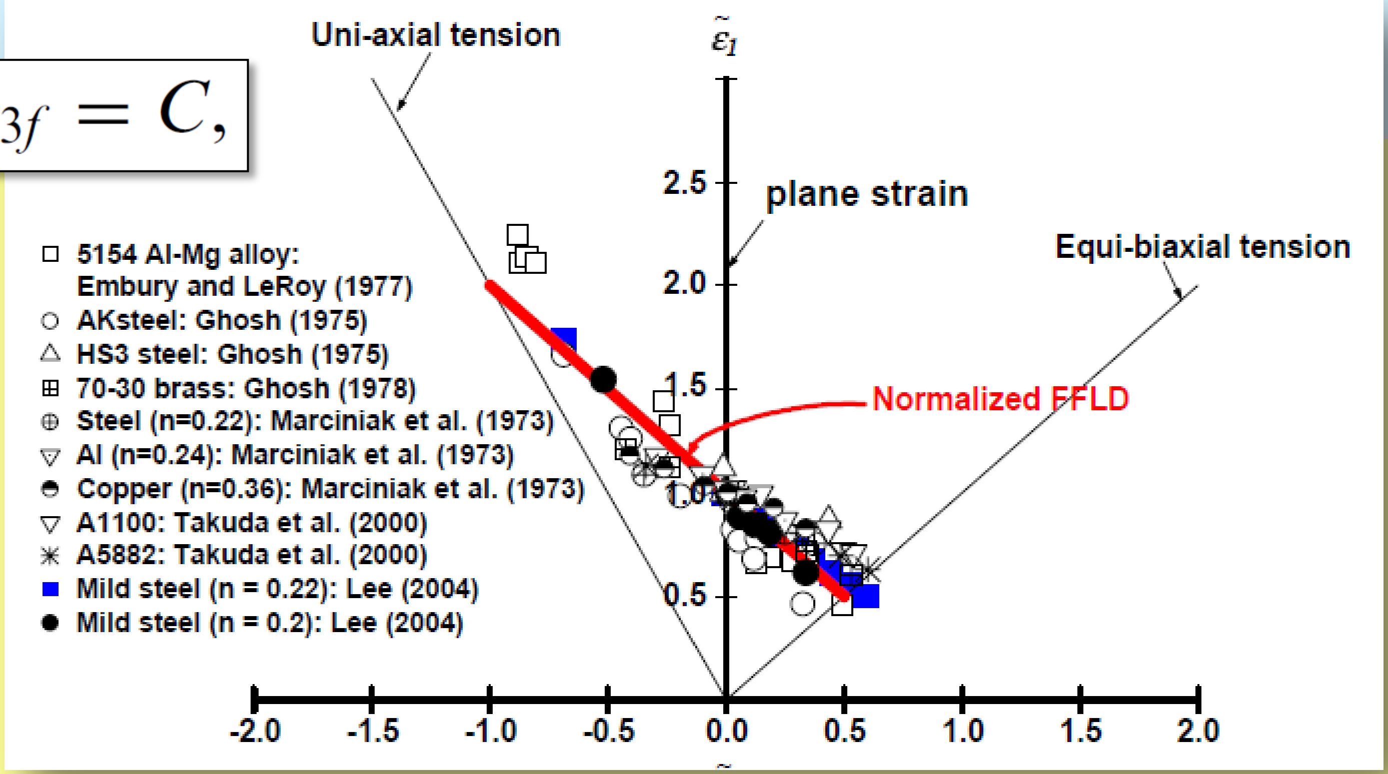
$$\bar{\varepsilon} = \bar{\varepsilon}_f \, .$$

*For incompressible materials*

$$\bar{\varepsilon} = \sqrt{\frac{2}{3}}\sqrt{\varepsilon_1^2 + \varepsilon_2^2 + \varepsilon_3^2},$$

***Fracture Forming Limiting Diagram (FFLD)***

$$\varepsilon_{1f} + \varepsilon_{2f} = -\varepsilon_{3f} = C,$$




*Wierzbicki, T., Bao, Y., Lee, Y.W., Bai, Y., 2005. Calibration and evaluation of seven fracture models. Int. J. Mech. Sci. 47, 719–743*

# Deformation based criteria + triaxiality factor

***Johnson-Cook (J-C)***

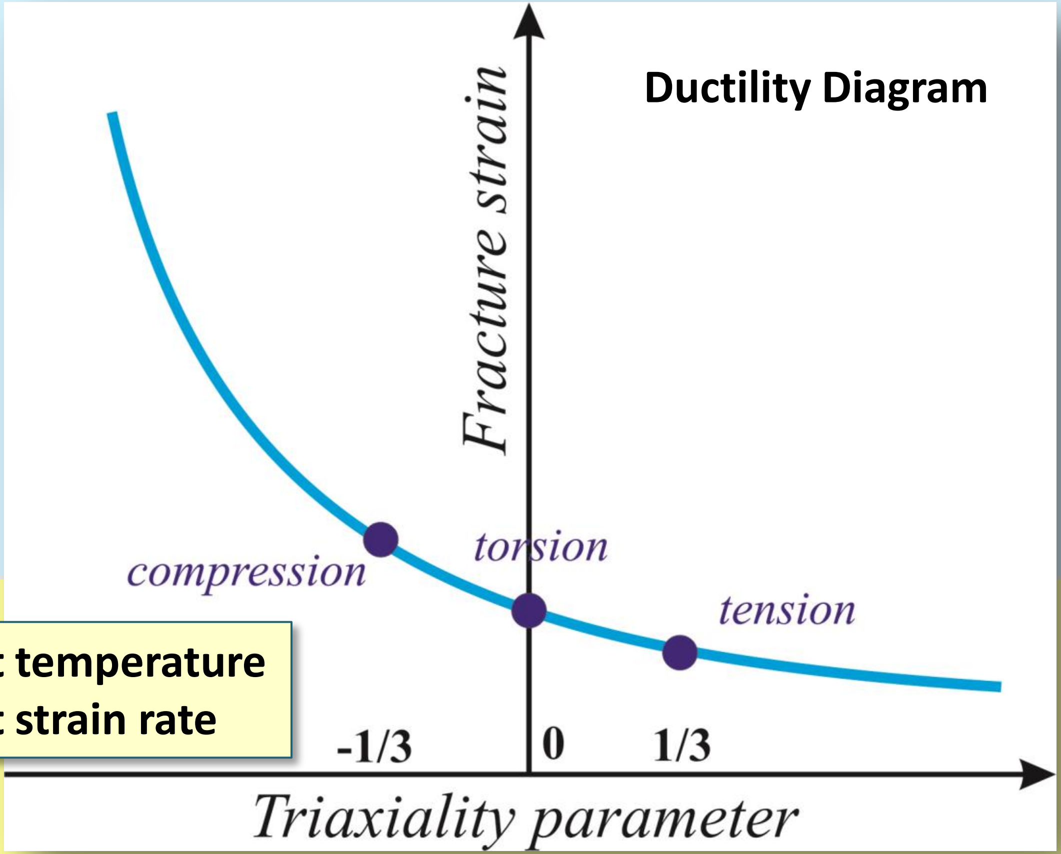
$$\bar{\varepsilon}_f = C_1 + C_2 \exp(C_3 \eta),$$

$$\eta = \frac{\sigma_m}{\bar{\sigma}}$$

*Triaxiality parameter*

$$\sigma_m = \frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3)$$

$$\bar{\sigma} = \frac{\sqrt{2}}{2}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2}$$




**Constant temperature**
**Constant strain rate**

***G.D.Kozlov***

$$\bar{\varepsilon}_f = \bar{\varepsilon}_{ft} \cdot e^{-3\eta}$$

***G.D.Del'***

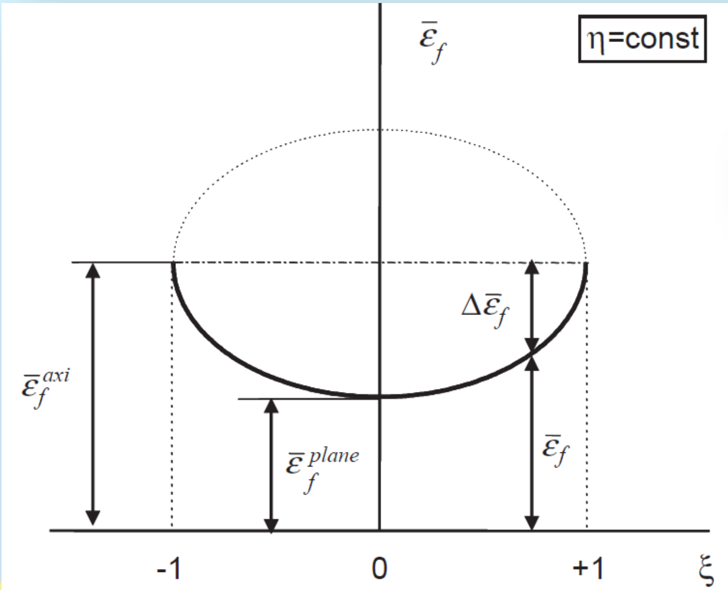
$$\bar{\varepsilon}_f = \frac{\bar{\varepsilon}_{fc} \cdot \bar{\varepsilon}_{ft}}{\bar{\varepsilon}_{fc} + 3\eta(\bar{\varepsilon}_{fc} - 2.72\bar{\varepsilon}_{ft})} \cdot e^{-3\eta}$$

$\bar{\varepsilon}_{fc}$ - *Fracture strain in compression*

$\bar{\varepsilon}_{ft}$ - *Fracture strain in torsion*

***More general theories***

# Material ductility dependence on triaxiality and deviatoric state




***Xue–Wierzbicki***

$$\bar{\varepsilon}_f = F(\eta, \xi) = C_1 e^{-C_2\eta} - (C_1 e^{-C_2\eta} - C_3 e^{-C_4\eta})(1 - \xi^{1/n})^n.$$

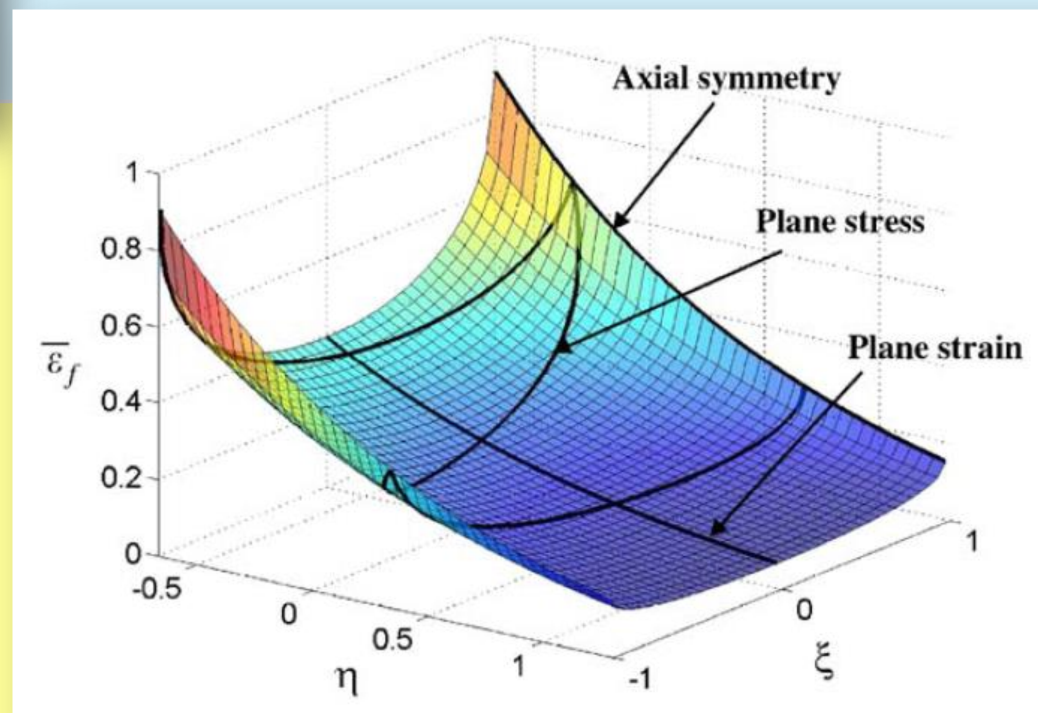
$$\xi = \frac{27}{2}\frac{J_3}{\bar{\sigma}^3}$$

*Deviatoric state parameter*

$$J_3 = s_1 s_2 s_3.$$

*The fracture criteria*

$$\int_0^{\bar{\varepsilon}_f} \frac{d\bar{\varepsilon}}{F(\eta, \xi)} = 1,$$




*Wierzbicki, T., Bao, Y., Lee, Y.W., Bai, Y., 2005. Calibration and evaluation of seven fracture models. Int. J. Mech. Sci. 47, 719–743*

# Workability Resource of the Material and its Assessment

***Main ideas:***

- *Any plastic deformation is accompanied by creation and development of the micro-defects.*
- *The process of creation , development or recovery of the defects depends on the loading history.*
- *Every material has certain Resource (Reserve) of Workability (RW) which reduces during the plastic deformation due to Damage Accumulation .*
- *Resource of Workability depends on the material properties and conditions of loading.*
- *The state of the material at any stage of the deformation process can be assessed by the Resource Utilization Parameter (RUP)*
- *Material fails when Resource of Workability is exhausted (RUP=1).*

***V.L.Kolmogorov***

$$\Psi(\bar{\varepsilon}) = \int_0^{\bar{\varepsilon}} \frac{d\bar{\varepsilon}}{\bar{\varepsilon}_f(\eta)}$$

***Resource Utilization Parameter (RUP)***

# Resource Utilization Parameter

***V.L.Kolmogorov***

$$d\psi = d\psi_1 + d\psi_2$$

$$d\psi_1 = c_1 \frac{d\bar{\varepsilon}}{\bar{\varepsilon}_f}$$

*Related to the development of the defects*

$$d\psi_2 = -c_2 d\bar{\varepsilon}$$

*Related to the recovery of the defects*

***V.A.Ogorodnikov***

$$d\psi = \frac{n\psi^{1-\frac{1}{n}} d\bar{\varepsilon}}{\bar{\varepsilon}_f(\eta)} - b\left(\psi - \psi_m^2\right)$$

***Yu.G.Kalpin et al. (combined criteria)***

***material hardening is assumed***

$$d\psi = \left[ c(\bar{\sigma} - \bar{\sigma}_0)e^{-c\bar{\varepsilon}} + \frac{1-(\bar{\sigma} - \bar{\sigma}_0)e^{-c\bar{\varepsilon}_f}}{\bar{\varepsilon}_f} \right] d\bar{\varepsilon}$$

***Kalpin,Yu.G., Perfilov, V.I., Petrov, P.A., Ryabov, V.A., Filipov, Yu.K., 2011. Deformation resistance and plasticity in metal forming. Mashinostroenie, Moscow, 243p.***

***V.G. Burdukovsky , V.L.Kolmogorov***

$$d\psi = \frac{c \cdot d\bar{\varepsilon}}{(1-\psi)^{\beta} \bar{\varepsilon}_f(\eta)}$$

***V.G. Burdukovsky et al. Journal of Materials Processing Technology 55 (1995) 292 295***

***R.A.Vasin, P.A.Mossakovsky (tensor variant of the model)***

$$\dot{\psi}_{ij} = \frac{1}{2W}\left(\alpha_{ij}\dot{\varepsilon}_{kj}^{p} + \alpha_{kj}\dot{\varepsilon}_{ij}^{p}\right) - \lambda\psi_{ij}$$

$W$ – *fracture energy*

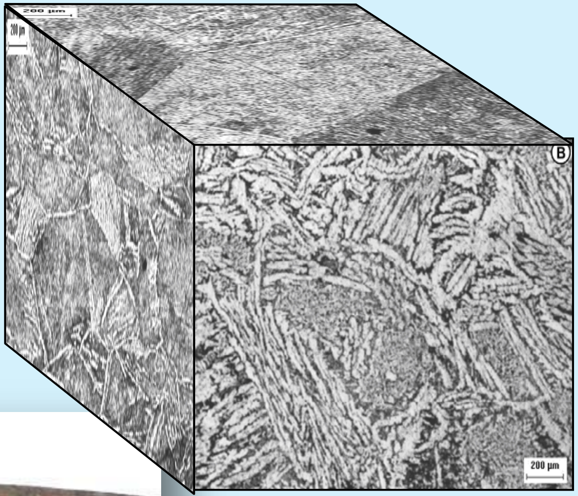
$\alpha_{ij}$ – *deviator of residual microstress*

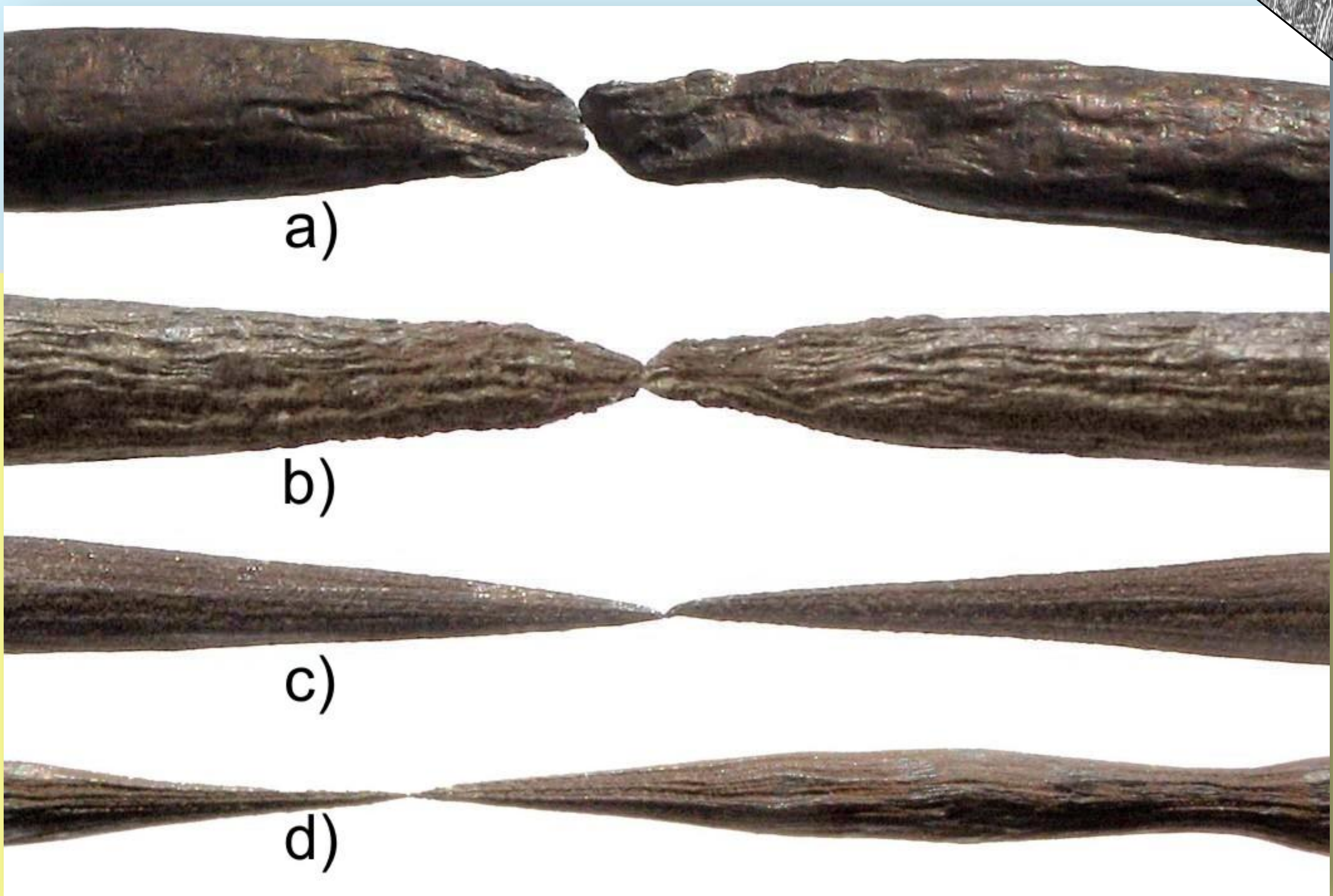
$\varepsilon_{ij}^{p}$ – *inelastic strains*

***Vasin, R.A., Mossakovskii, P.A., 2011. Journal of Applied Mathematics and Mechanics 75, 5– 9***

# The effect of the Temperature and Strain Rate

***Material: Ti-6Al-4V, Isothermal tension, const. strain rate.***
***Initial microstructure: Widmanstätten, pr. $\beta$ gr.~200μm***






***T=950°C***

$\dot{\varepsilon} = 10^{-4} s^{-1}$ δ~120%

***T=900°C***

$\dot{\varepsilon} = 5 \cdot 10^{-4} s^{-1}$ δ~170%

$\dot{\varepsilon} = 10^{-4} s^{-1}$ δ~200%

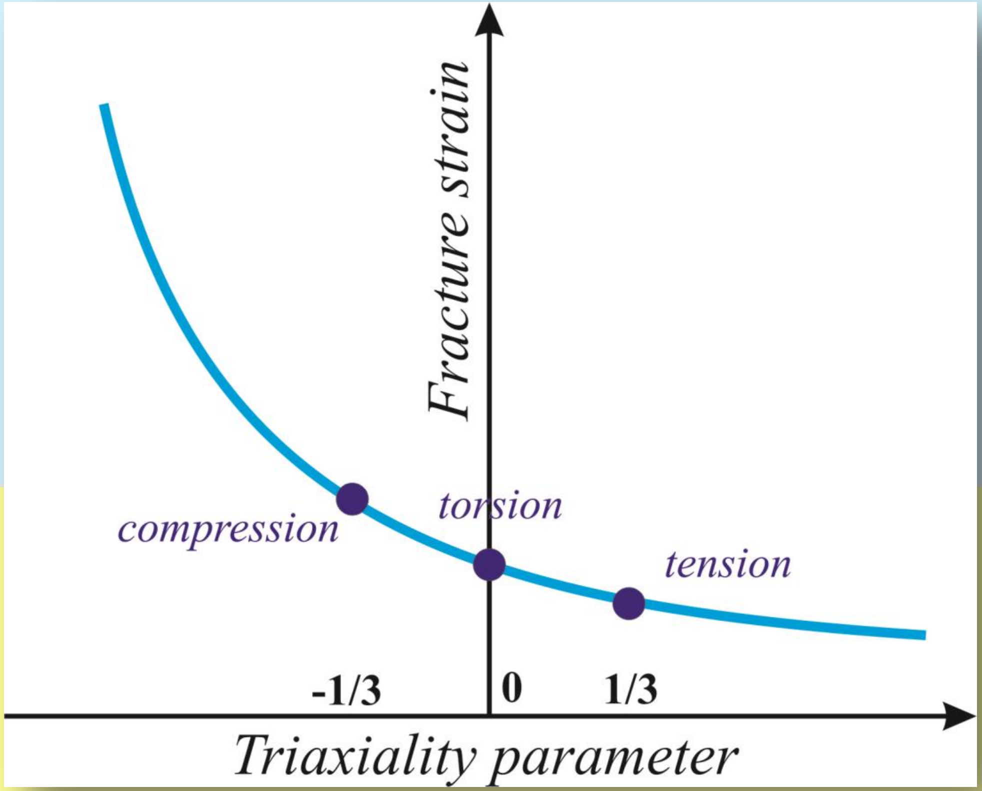
***T=850°C***

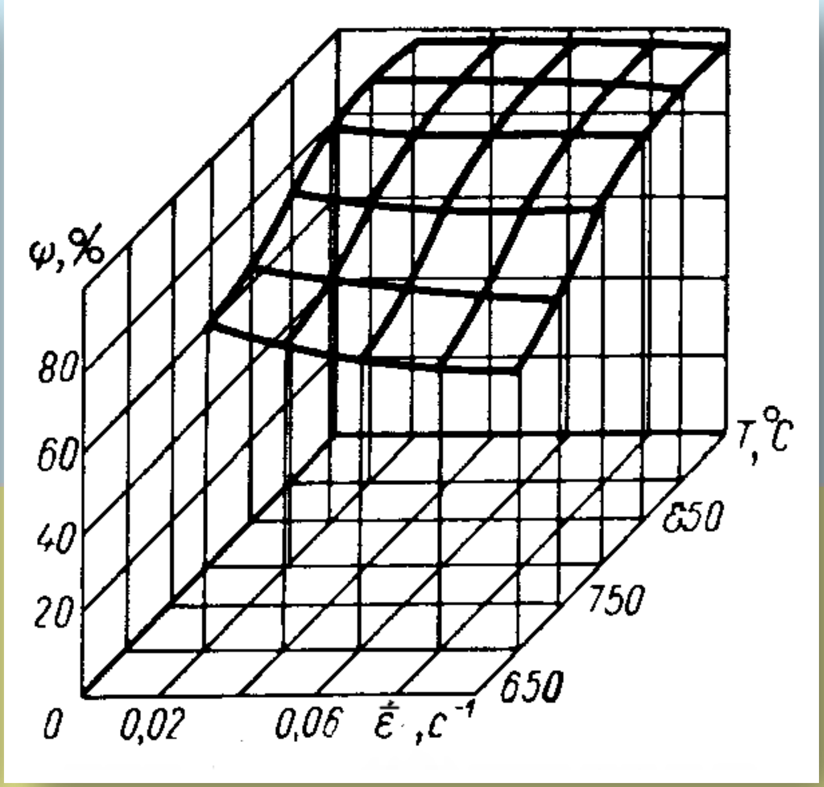
$\dot{\varepsilon} = 10^{-4} s^{-1}$ δ~190%

$\dot{\varepsilon} = 2.5 \cdot 10^{-4} s^{-1}$ δ~240%

$\dot{\varepsilon} = 5 \cdot 10^{-4} s^{-1}$ δ~170%

# Proposed approach for taking into account temperature and Strain Rate



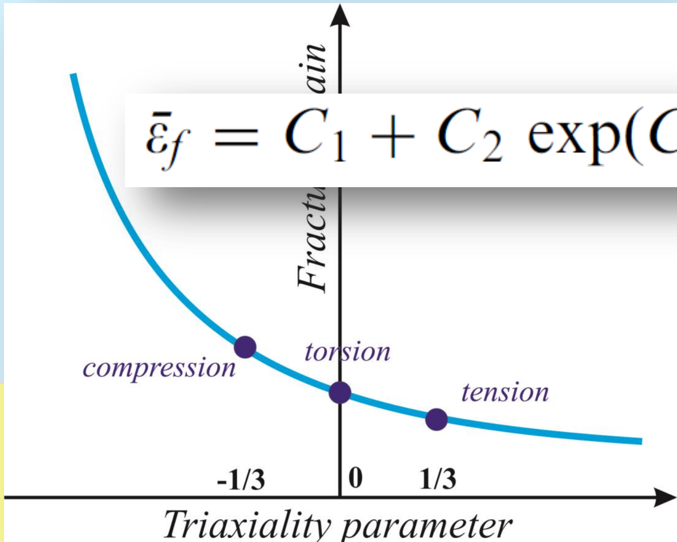

$$\bar{\varepsilon}_f = f(\eta, T, \dot{\bar{\varepsilon}}, \ldots.)$$ **Hypothesis** $$\bar{\varepsilon}_f = f(\eta, T, \dot{\bar{\varepsilon}}) = \chi(\eta)\cdot\phi(T, \dot{\bar{\varepsilon}})$$

**or** $$\bar{\varepsilon}_f = \frac{\bar{\varepsilon}_{fc}\cdot\bar{\varepsilon}_{ft}}{\bar{\varepsilon}_{fc} + 3\eta\left(\bar{\varepsilon}_{fc} - 2.72\bar{\varepsilon}_{ft}\right)}\cdot e^{-3\eta},\ \ \bar{\varepsilon}_{fc[t]} = \phi_{c[t]}(T, \dot{\bar{\varepsilon}})$$

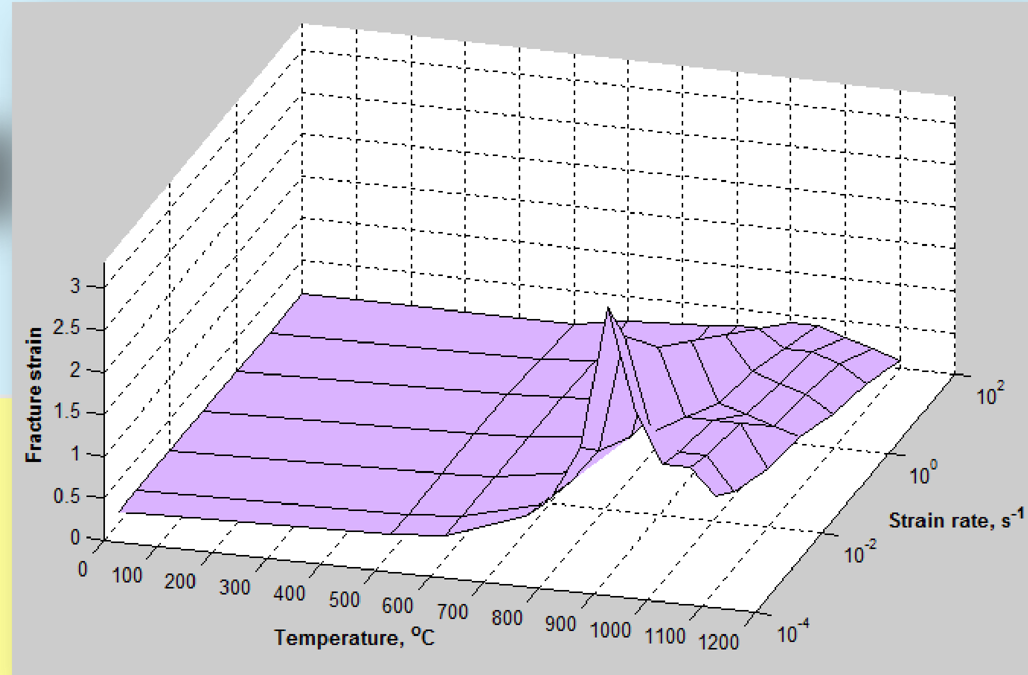
***Possible modification of G.D.Del' approximation***

# Simulation of the modified deformation-based criteria

***Calibration of the fracture strain equation***




$$\bar{\varepsilon}_f = C_1 + C_2 \exp(C_3\eta),$$




*3 tests: tension, compression, torsion*

| | | | |
|---|---|---|---|
| Fracture strain | $\bar{\varepsilon}_{ften}$ | $\bar{\varepsilon}_{fc}$ | $\bar{\varepsilon}_{ftor}$ |

$$C^* = \frac{\bar{\varepsilon}_{ftor} - \bar{\varepsilon}_{ften}}{\bar{\varepsilon}_{fcomp} - \bar{\varepsilon}_{ftor}} \quad C_3 = 3\ln\left(\frac{\bar{\varepsilon}_{ftor} - \bar{\varepsilon}_{ften}}{\bar{\varepsilon}_{fcomp} - \bar{\varepsilon}_{ftor}}\right)$$

$$\bar{\varepsilon}_f = \frac{\left(C_1 + C_2 \exp\left(C_3\eta\right)\right)}{\bar{\varepsilon}_{ften}} \cdot \varepsilon^*\left(T, \dot{\bar{\varepsilon}}\right)$$

$$C_2 = \frac{\bar{\varepsilon}_{ftor} - \bar{\varepsilon}_{ften}}{1 - C^*} \qquad C_1 = \bar{\varepsilon}_{ftor} - C_2$$

# *The range of applicability…* **The effect of microstructure** *e.g.,Ti-6Al-4V*

***Fine-grained material***

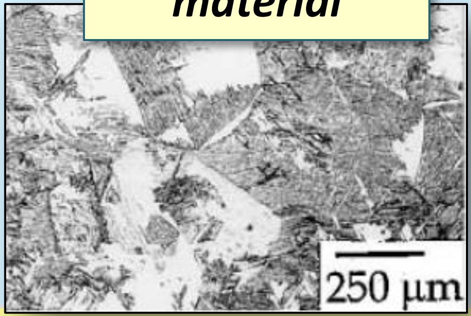

Seshacharyulu,T. et al, 2000, Mat. Sci. Eng. A284 184–194
Seshacharyulu,T. et al., 2002, Mat. Sci. Eng. A325 112–125

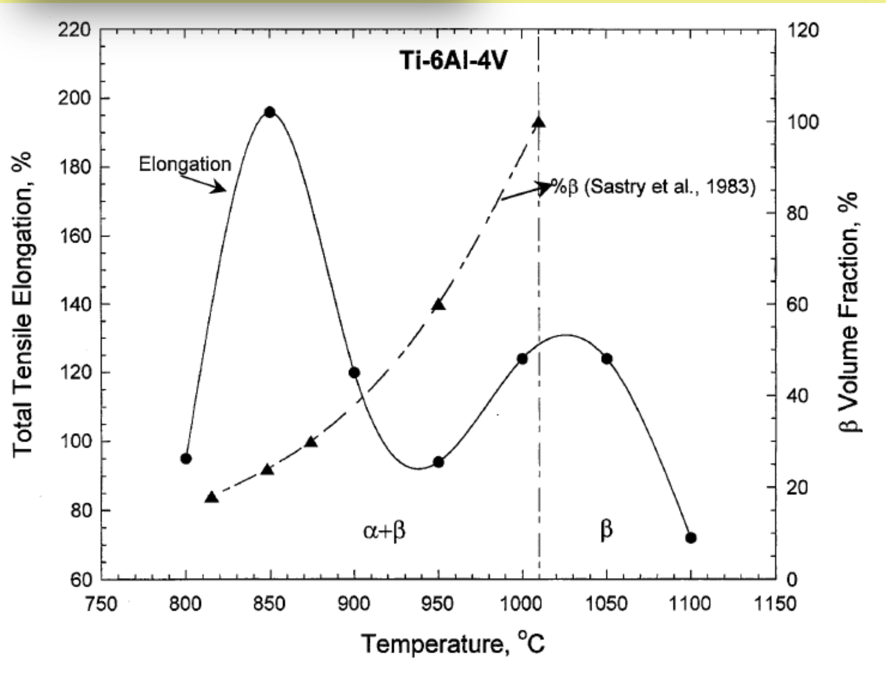
*Tension, constant strain rate 0.01 $s^{-1}$*

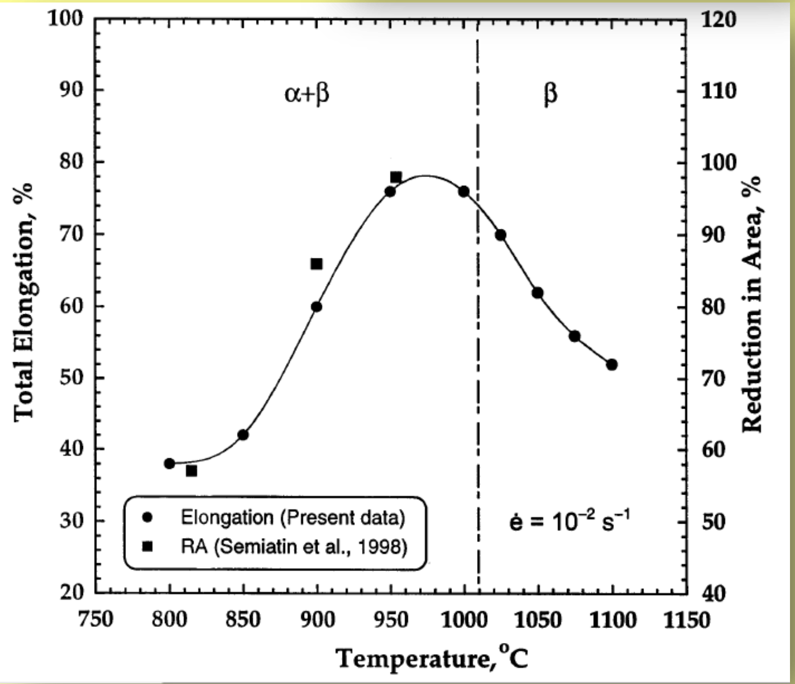
***Required modifications***

$$\varepsilon_f = f(\eta, T, \dot{\varepsilon}, D\ldots)$$
$$A = A(\eta, T, \dot{\varepsilon}, D\ldots)$$

***Coarse-grained material***



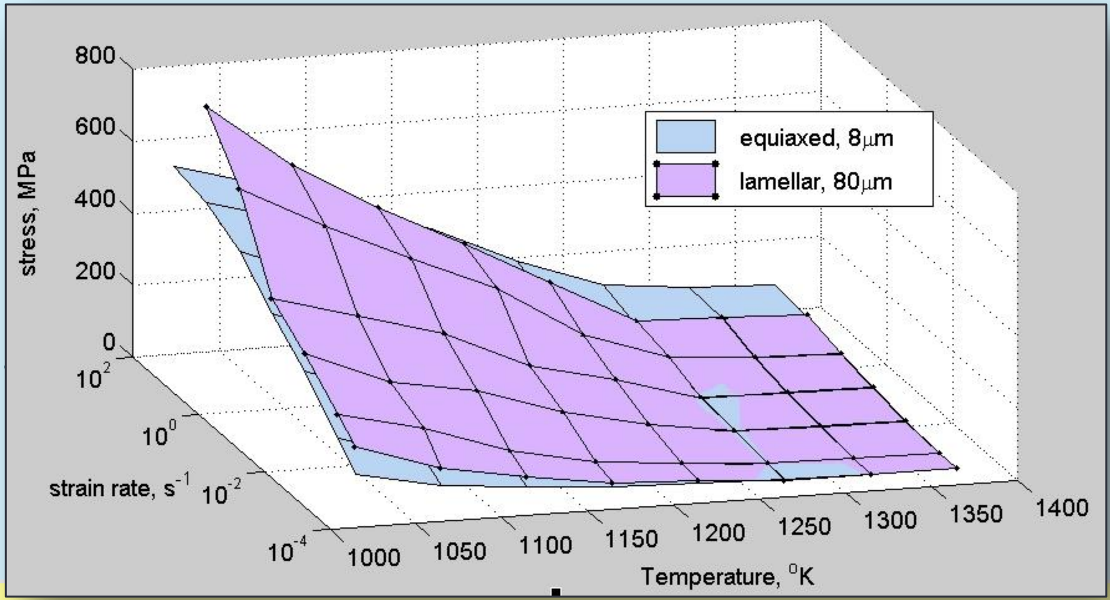



# Rheological model

$$\sigma = A\dot{\varepsilon}^m \exp\left(\frac{Q}{RT}\right)\left(\frac{D}{d_0}\right)^k$$

*A, m, Q & k – dynamic parameters: for each temperature and strain rate different set of parameters*




$$\dot{D} = \begin{cases} t_g \exp\left(-\frac{Q}{RT}\right) & \text{if } D \le D_m \\ (C\frac{\sigma}{D^2} + t_d)\cdot \exp\left(-\frac{Q}{RT}\right) & \text{if } D_m \le D \le D_{cr} \\ 0, \quad D = 0.7 \cdot D_{cr}, & \text{if } D \ge D_{cr} \end{cases}$$

for the static growth

for the deformation growth

for the integral refinement

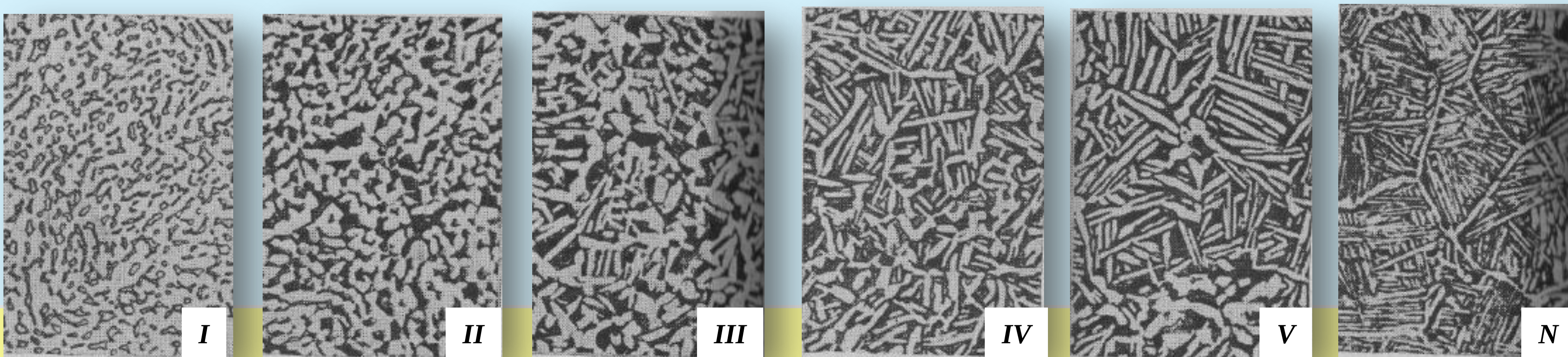
$$D_{cr} = D_1 + D_{cr0} \exp\left(-B_1 \int \sigma \cdot \dot{\varepsilon} \cdot dt\right)$$

*$D_{cr}$ determines the critical effective grain size for the start of refinement*

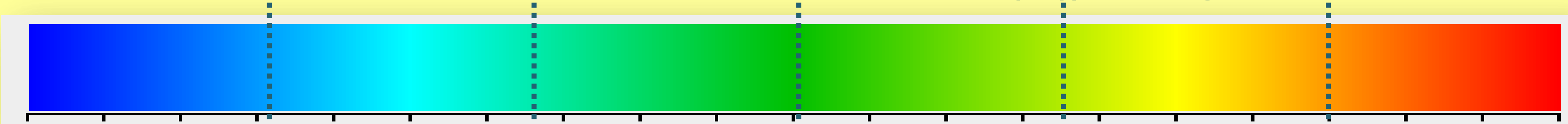
*O.I.Bylya, M.K Sarangi, N.V.Ovchinnikova, R.A.Vasin, E.B.Yakushina, P.L.Blackwell, FEM simulation of microstructure refinement during severe deformation, IOP Conf. Series: Materials Science and Engineering 63 (2014) 012033*

# What is the meaning of the "Effective Grain Size" for two-phase alloys?

*All morphologies appearing during the process are divided into N grades*




*and associated with the continuous scale of effective grain sizes*



| $D_I \le D \le D_{II}$ | $D_{II} < D \le D_{III}$ | $D_{III} < D \le D_{IV}$ | $D_{IV} < D \le D_V$ | $D_V < D \le D_{VI}$ | $D_N < D \le D_0$ |
|---|---|---|---|---|---|
| $X^{I}_{P\alpha}$ | $X^{II}_{P\alpha}$ | $X^{III}_{P\alpha}$ | $X^{IV}_{P\alpha}$ | $X^{V}_{P\alpha}$ | $X^{N}_{P\alpha}$ |
| $X^{I}_{S\alpha}$ | $X^{II}_{S\alpha}$ | $X^{III}_{S\alpha}$ | | | |
| $t^{I}_{S\alpha}$ | $t^{II}_{S\alpha}$ | $t^{III}_{S\alpha}$ | | | |
| …… | …… | …… | …… | …… | …… |

**Supplementary parameters:**

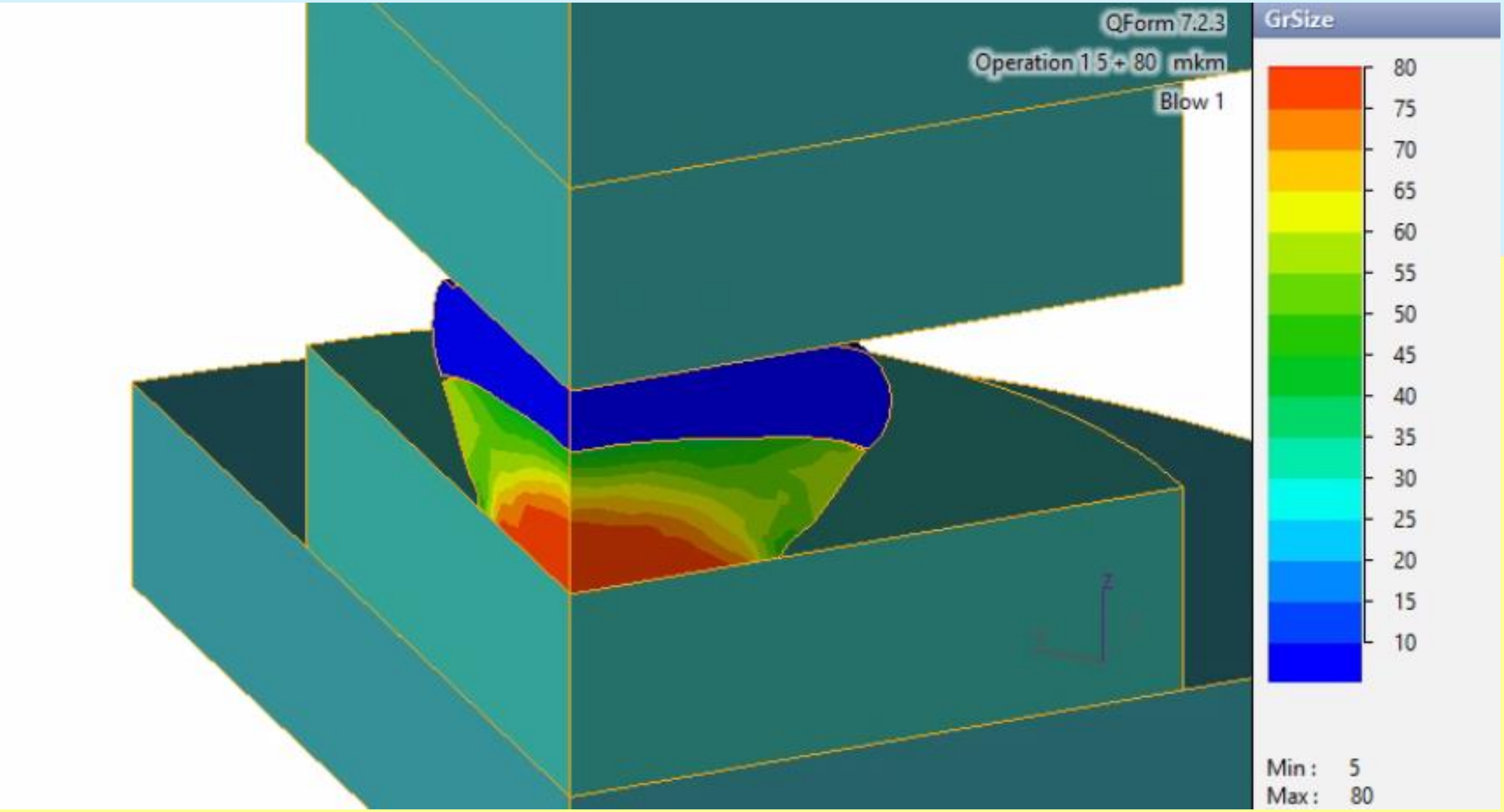
***$X_{P\alpha}$ and $X_{S\alpha}$ - fraction of primary and secondary $\alpha$-phase;***

***$t_{S\alpha}$ - thickness of secondary $\alpha$ lath; …***

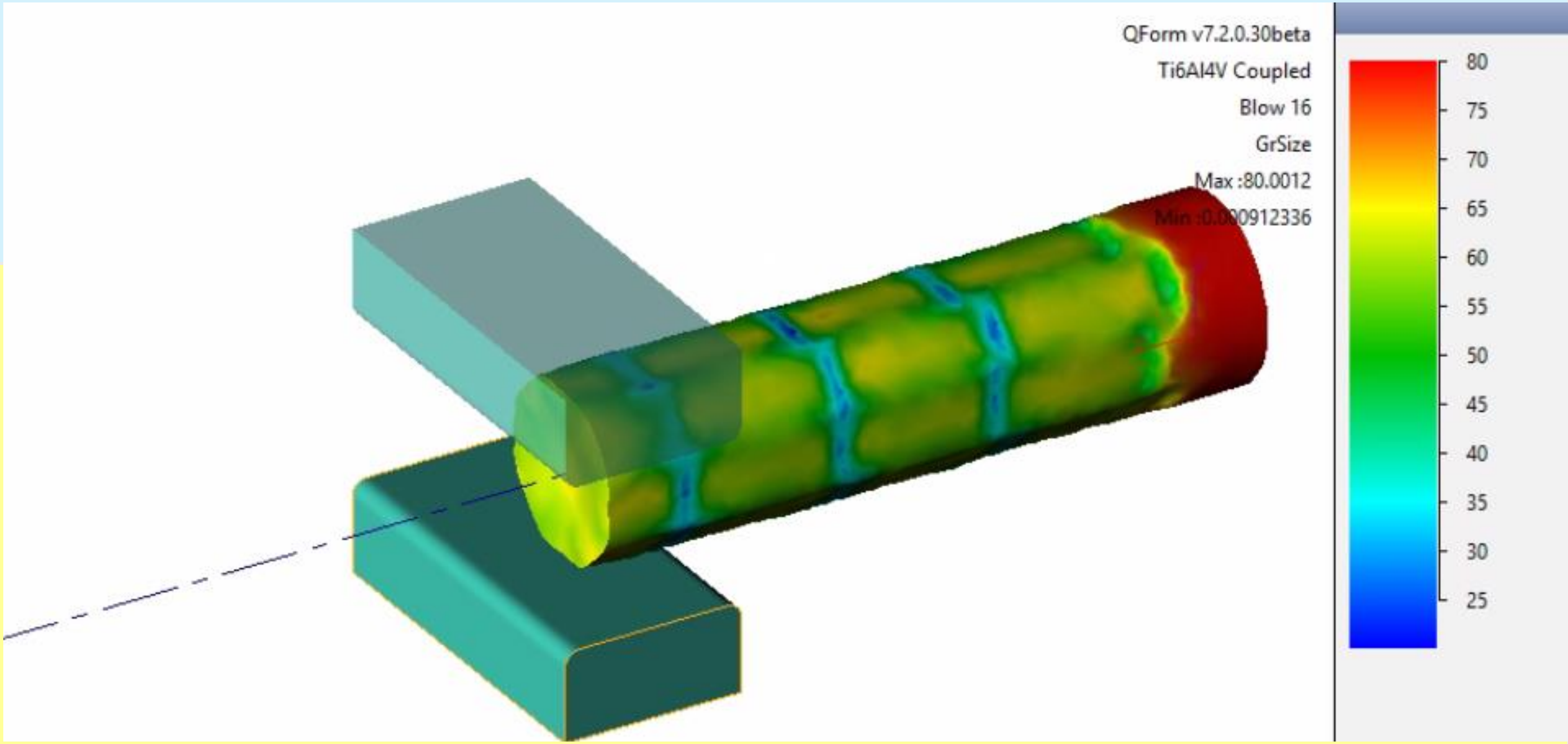
# Influence of the grain size on the flow stress (Ti6Al4V).

## Inverse Hall-Petch effect in hot forming

**Initial grain size:**
**top billet 5 micron,**
**bottom billet 80 micron**



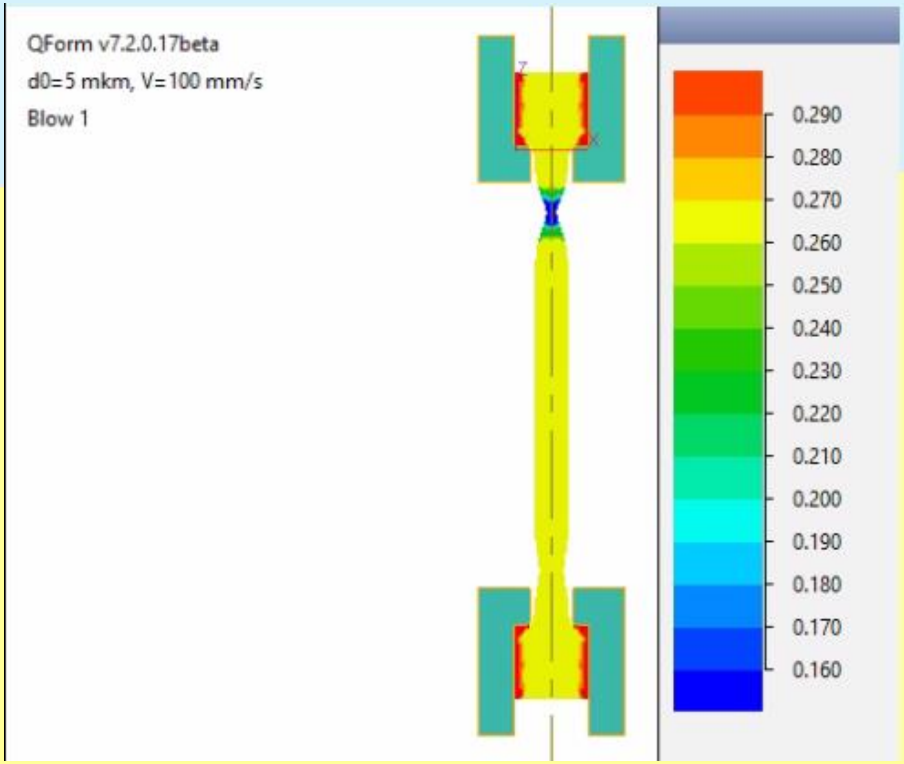
# Grain size distribution in cogging of Ti6Al4V bar (μm)



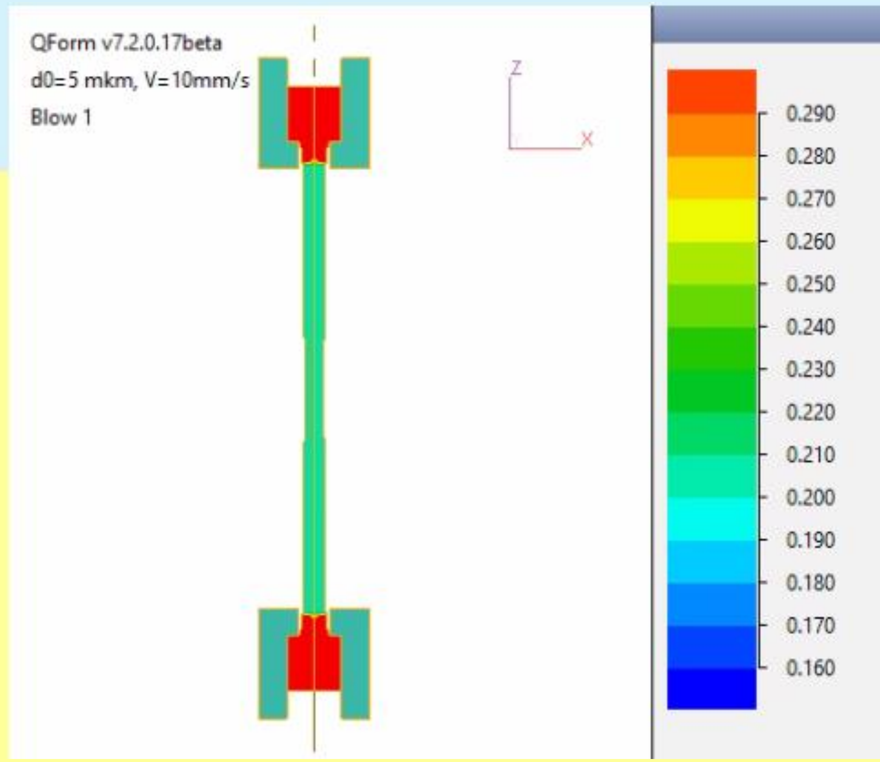
# Microstructural modelling of TI6Al4V

## Strain rate sensitivity depends both on strain-rate and microstructure

**High tool velocity**

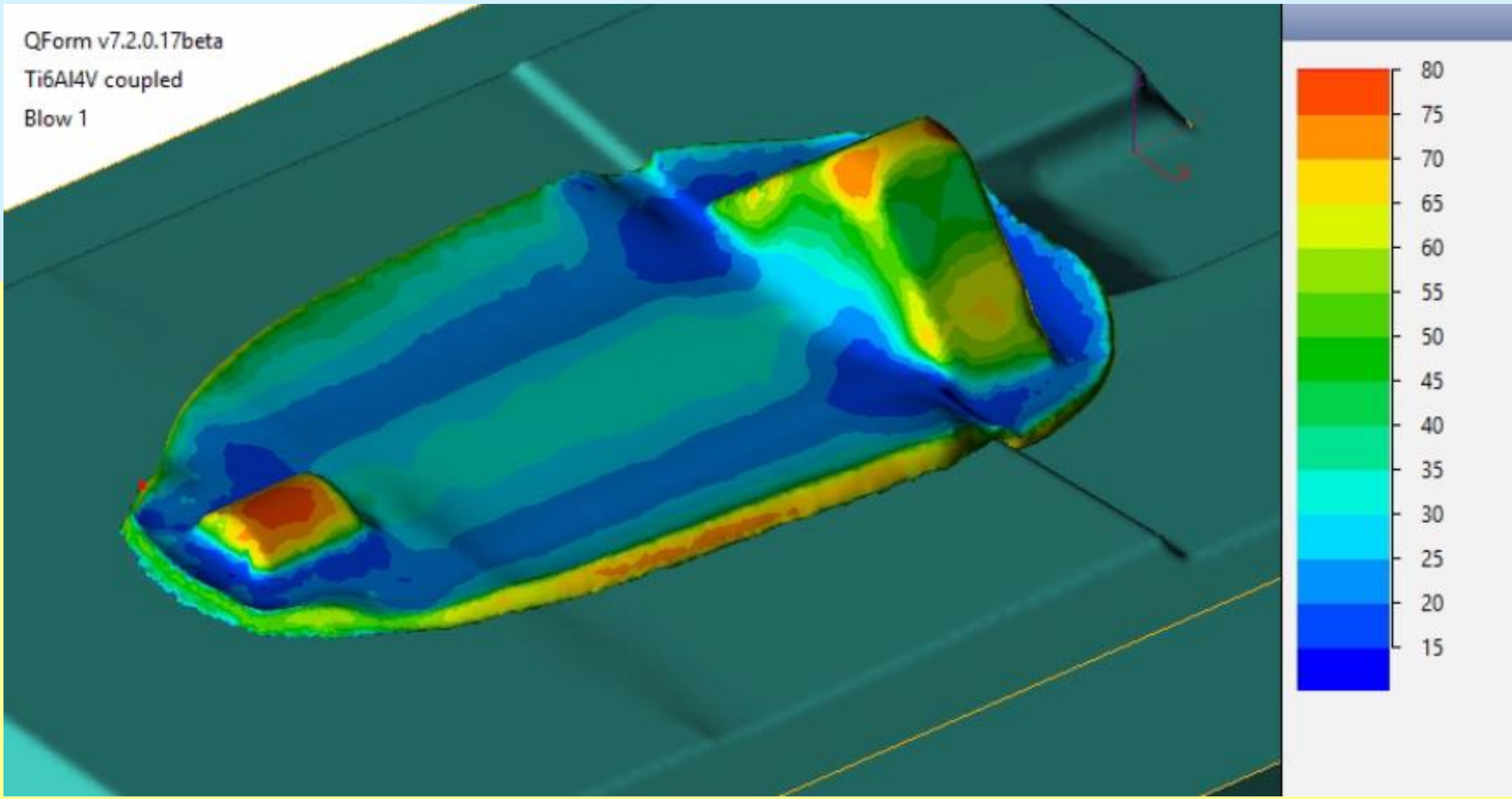



**Low tool velocity**

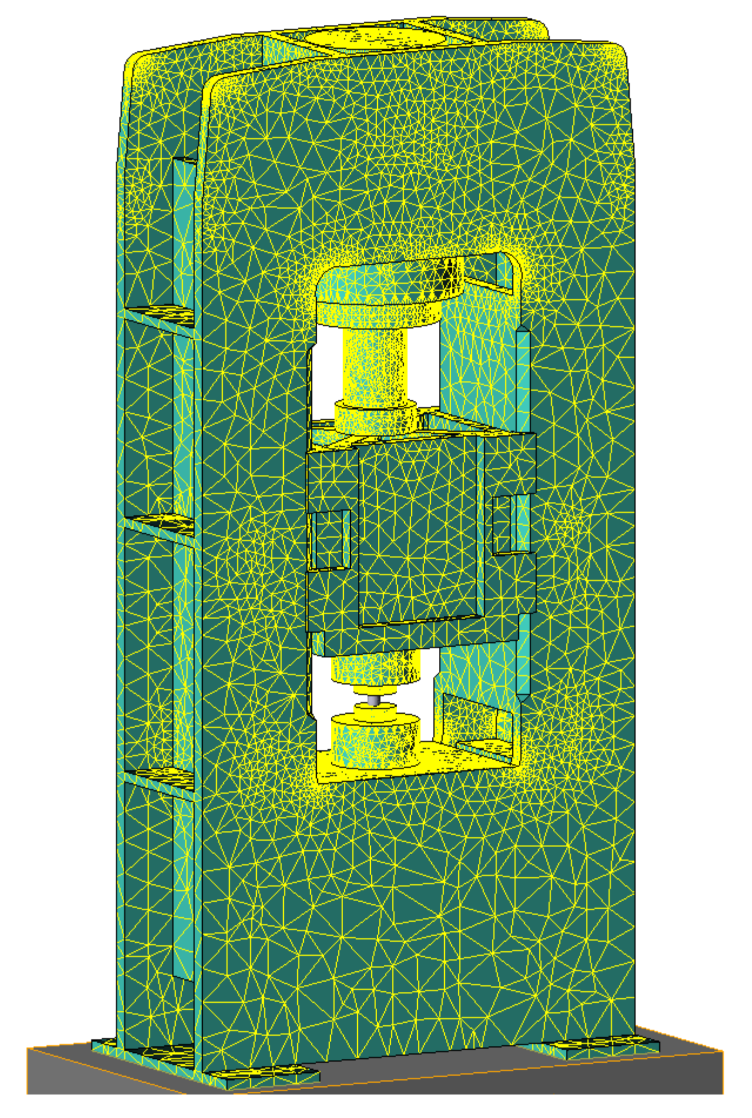


# Fully coupled model (equipment-die-workpiece-microstructure)

## Grain size distribution in the blade Ti6Al4V, µm



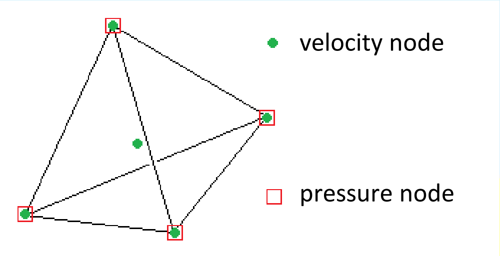
# Finite element mesh for coupled deformation and thermal problem



Mesh information:

plastic problem

low-order tetrahedron element
with 24 degree of freedom



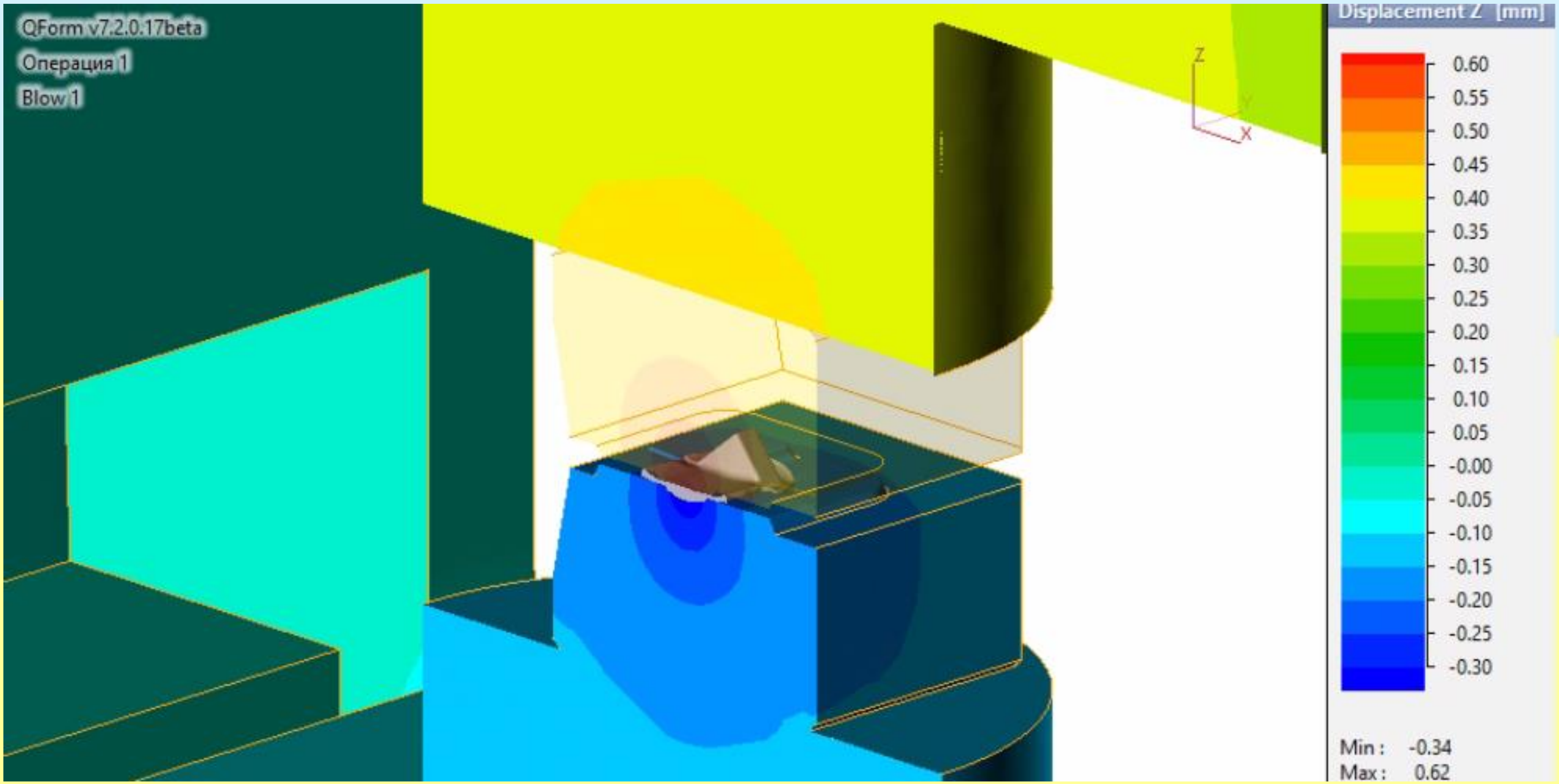

elastic problem

ordinary linear 4-node tetrahedron
element with 12 degrees of freedom
(3 displacements in node)

| Simulation part | Number of nodes | Number of elements |
|---|---|---|
| merged ram | 6449 | 23152 |
| merged frame | 14888 | 52021 |
| upper die | 25169 | 118057 |
| bottom die | 37810 | 185346 |
| workpiece | 3045… 26934 | 12158… 11677 |

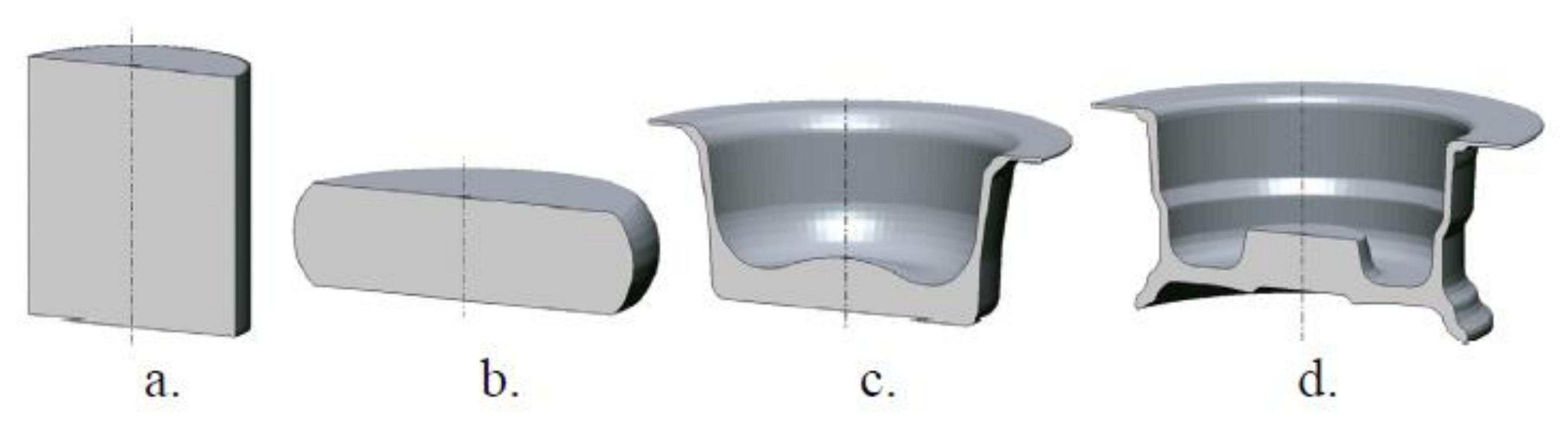
# Totally coupled model (equipment-die-workpiece-microstructure)

## Vertical displacement distribution in the die and die holder, mm



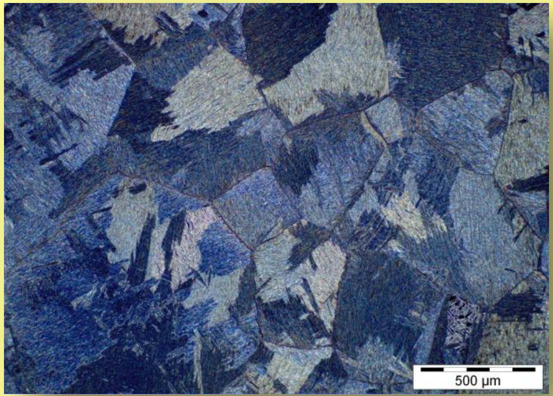
# Rough example of modified resourse assessment approach

## The problem of wheel disk forging (3 operations)




S.Stebunov, N.Biba, A.Ovchinnikov, V.Smelev, Application of QForm forging simulation system for prediction of microstructure of aluminum forged parts, *Computer Methods in Material Scuence*, **7**, No. 1, 1-5, 2007.

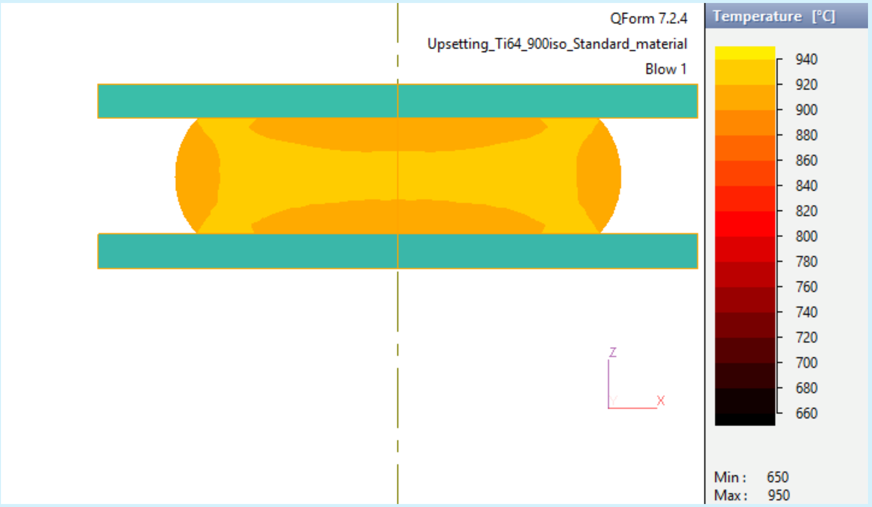
*Investigation of the perspectives of utilization of coarse grained materials in hot working*

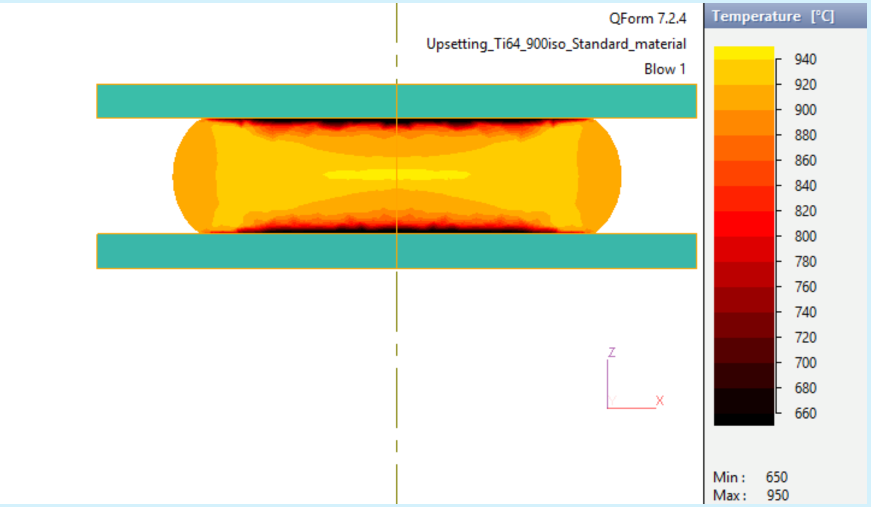



# Isothermal compression

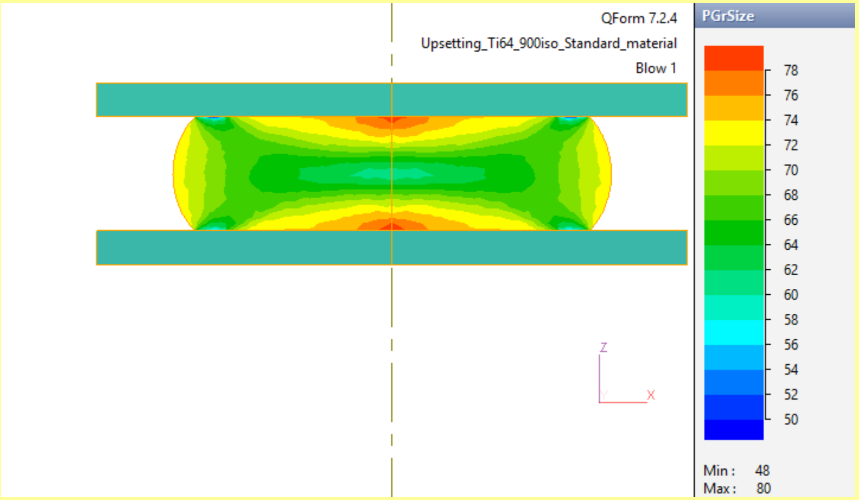
# Non-isothermal compression

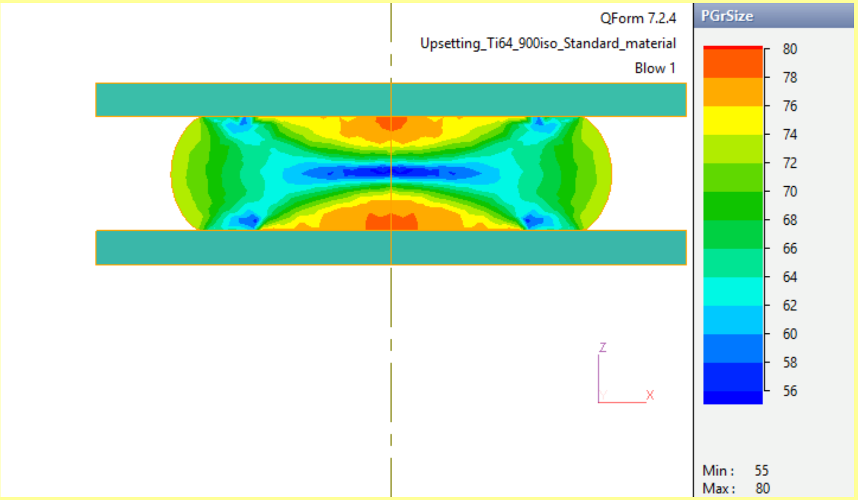
## Temperature distribution (initial temp=900C)




## Grain size distribution (initial grain size 80 mkm)



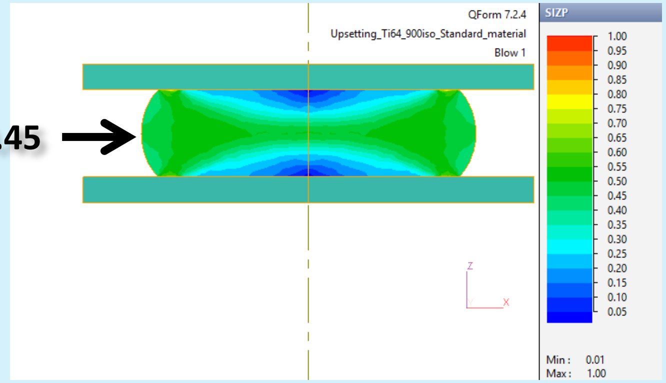



# *Isothermal compression* / *Non-isothermal compression*

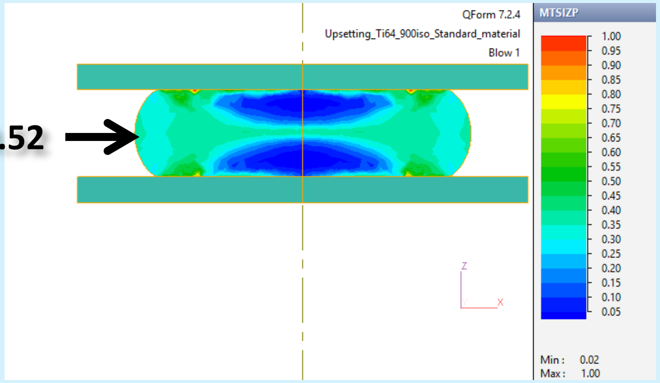
## Workability Resource Utilisation Parameter (RUP)

**No temperature and strain-rate influence**

0.45 →

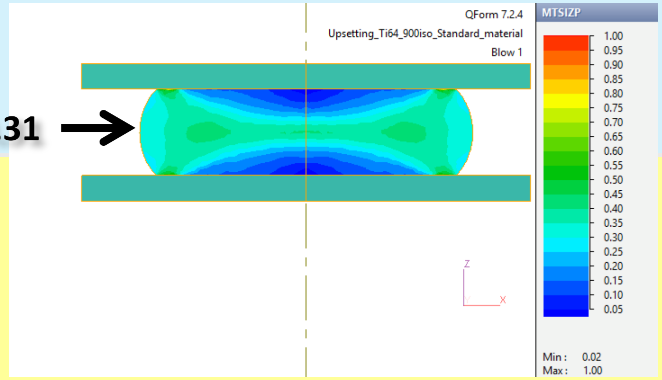



0.52 →

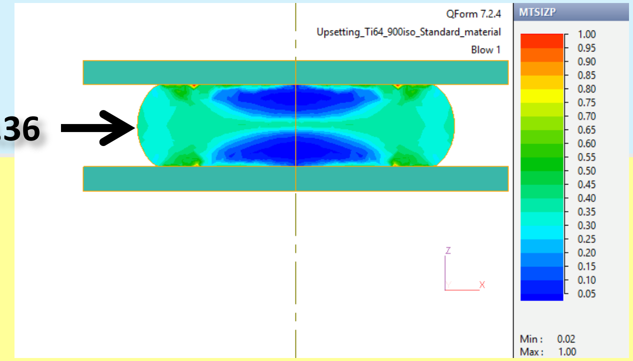



**Temperature and strain-rate influence**

0.31 →

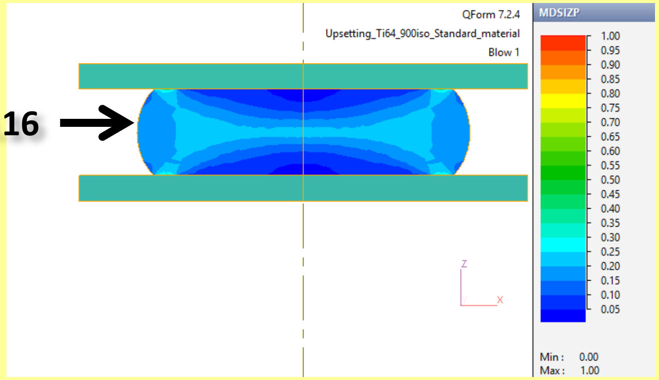



0.36 →

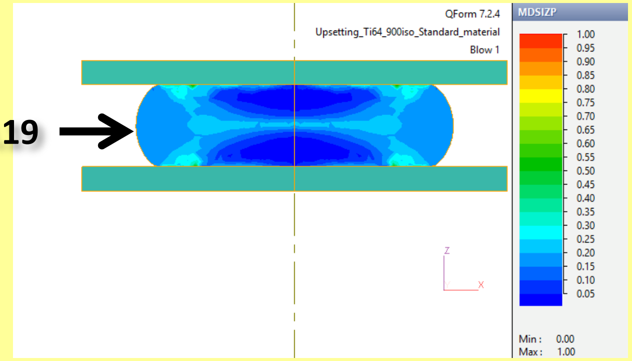



**Temperature and Strain-rate and grain size influence**

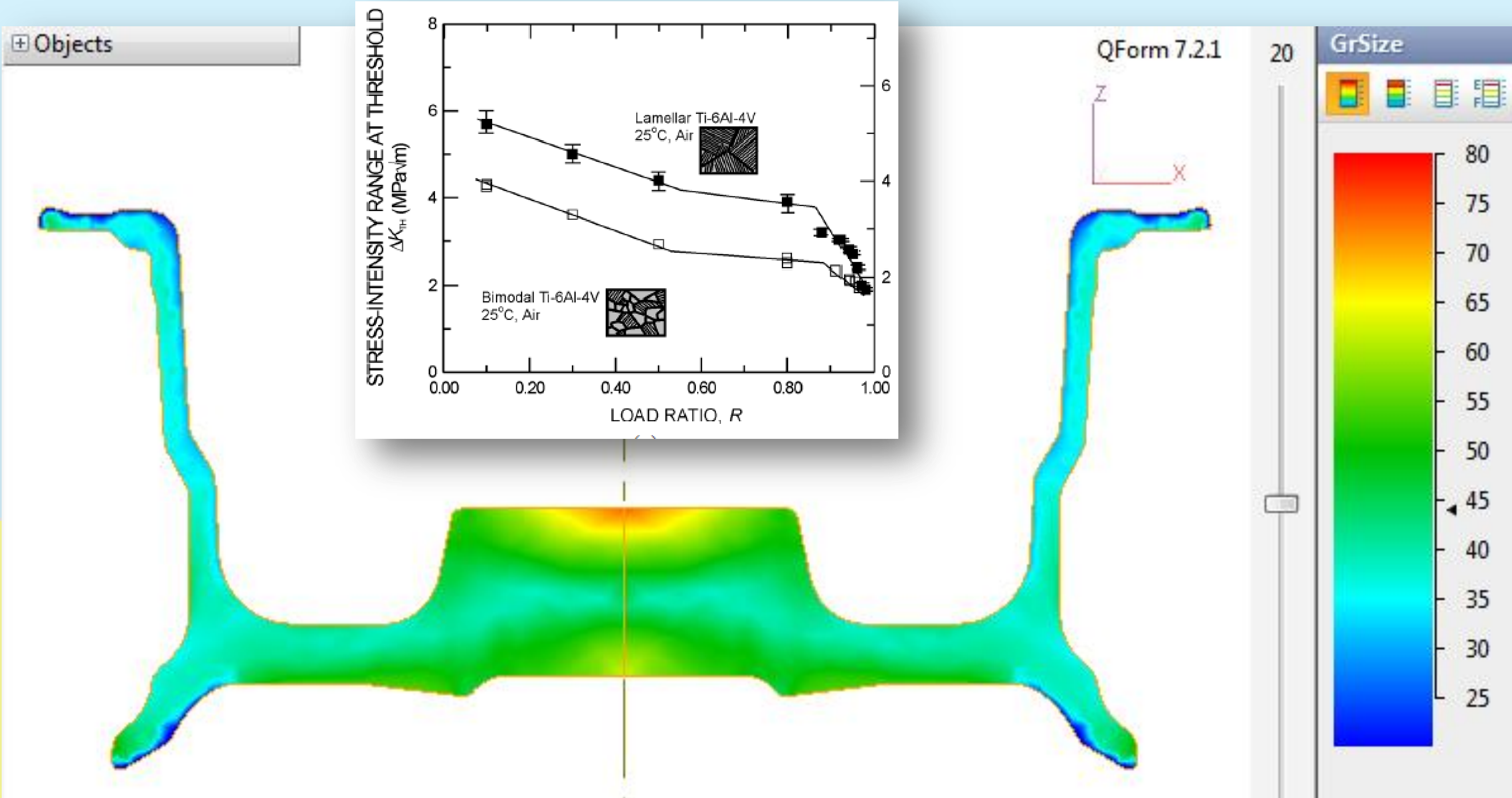
0.16 →




0.19 →

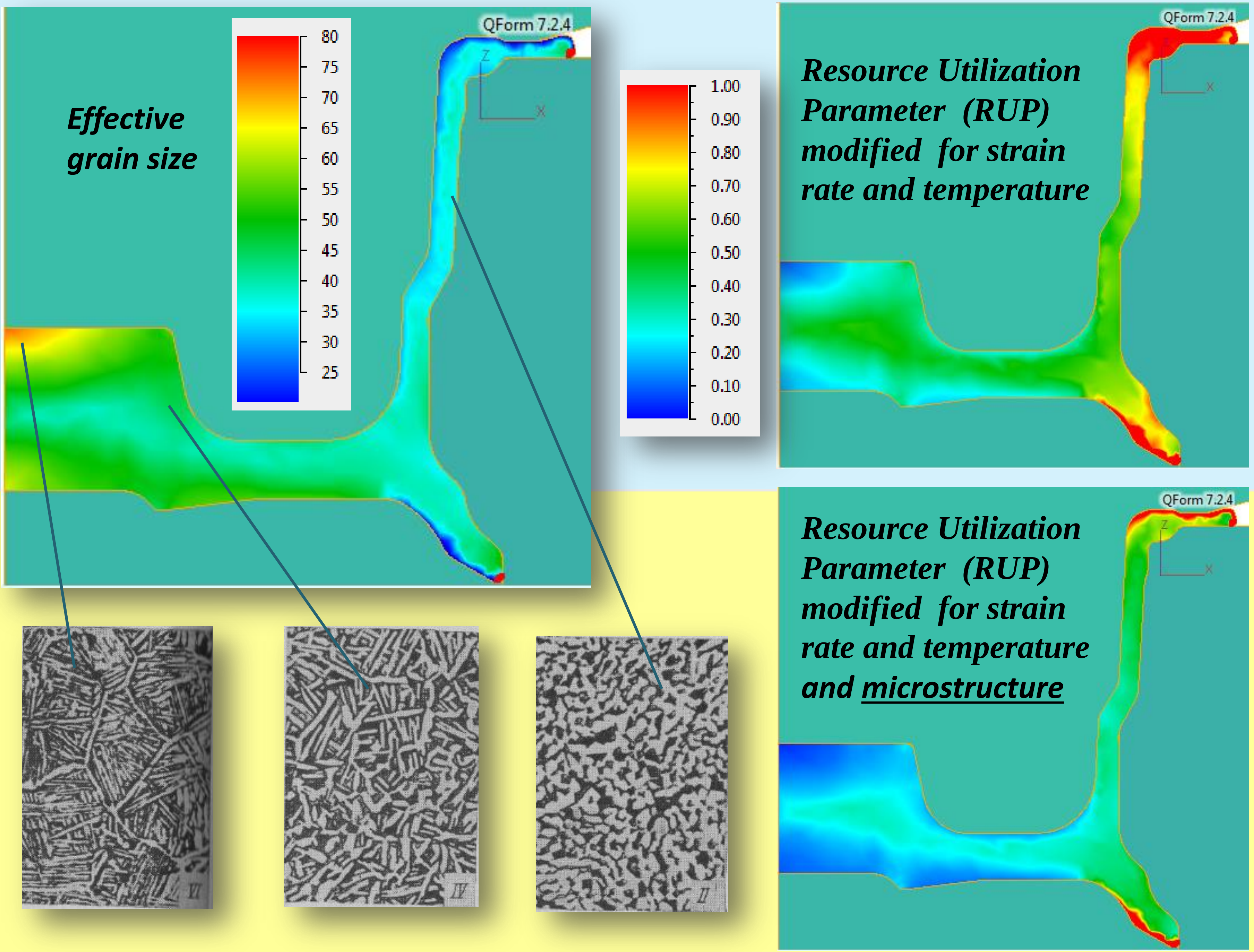


# Final effective grain size distribution




*R.K. NALLA, B.L. BOYCE, J.P. CAMPBELL, J.O. PETERS, and R.O. RITCHIE Influence of Microstructure on High-Cycle Fatigue of Ti-6Al-4V: Bimodal vs. Lamellar Structures, METALLURGICAL AND MATERIALS TRANSACTIONS A, VOLUME 33A, MARCH 2002—899*

*И.Ф.Аношкин, Г.А.Бочвар, В.А.Ливанов, И.С.Полькин, В.И.Моисеев, «Металлография титановых сплавов», Москва, «Металлургия», 1980, 464с.*



Effective grain size
80
75
70
65
60
55
50
45
40
35
30
25
QForm 7.2.4
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
QForm 7.2.4
Resource Utilization Parameter (RUP) modified for strain rate and temperature
QForm 7.2.4
Resource Utilization Parameter (RUP) modified for strain rate and temperature and microstructure
VI
IV
II

# Conclusions

- ***Strength-based criteria can be modified for accounting the influence of the temperature and strain rate, but the can’t be applied if deformation softening can take place.***

- ***The strain-based criteria type of Formability Limiting Curve don’t take into account the history of loading and hardly can be used for the processes with significant change of the triaxiality.***

- ***The models based on the idea of the Workability Resource and the Level of its Utilization look promising for the purpose of Continues Damage Accumulation Assessment***

# Conclusions

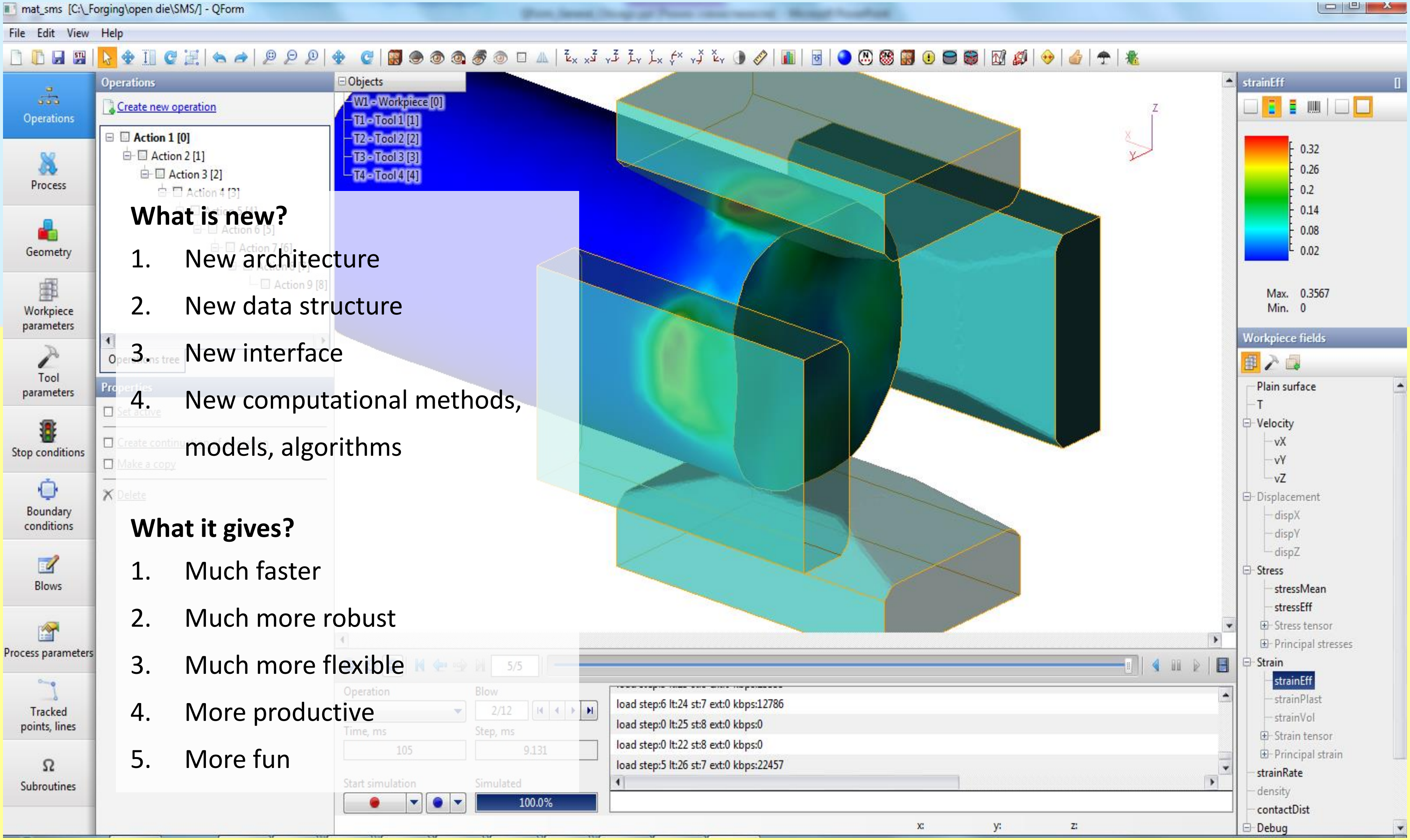
**However following issues have to be theoretically and experimentally investigated**:

- ✓ ***Which parameter characterizing the stress state (triaxiality, Lode-Nadai or deviatory state parameter) is the most appropriate for HOT WORKING processes, whether it is possible to use a single parameter.***
- ✓ ***What should be chosen as the measure of the Material Resource for the hot working – Fracture Strain, Energy Dissipation (Plastic Work) or something else.***
- ✓ ***The problem of additivity in non-liner models of RUP kinetics.***
- ✓ ***The hypothesis that the influence of triaxiality is independent from the effect of temperature and strain rate. This hypothesis has to be theoretically and experimentally investigated.***

**Good news: this work can be done much faster in case if community joins the efforts**

QForm UK

# New program QForm 7




**What is new?**

1. New architecture
2. New data structure
3. New interface
4. New computational methods, models, algorithms

**What it gives?**

1. Much faster
2. Much more robust
3. Much more flexible
4. More productive
5. More fun

## Easy programming of User's Defined Function (UDF) using Lua language

New technology **just-in-time compilation** (**JIT**), also known as **dynamic translation**

**UDF can be used**

- **In post-processor mode**
- **In coupled mode influencing the material flow pattern and properties**

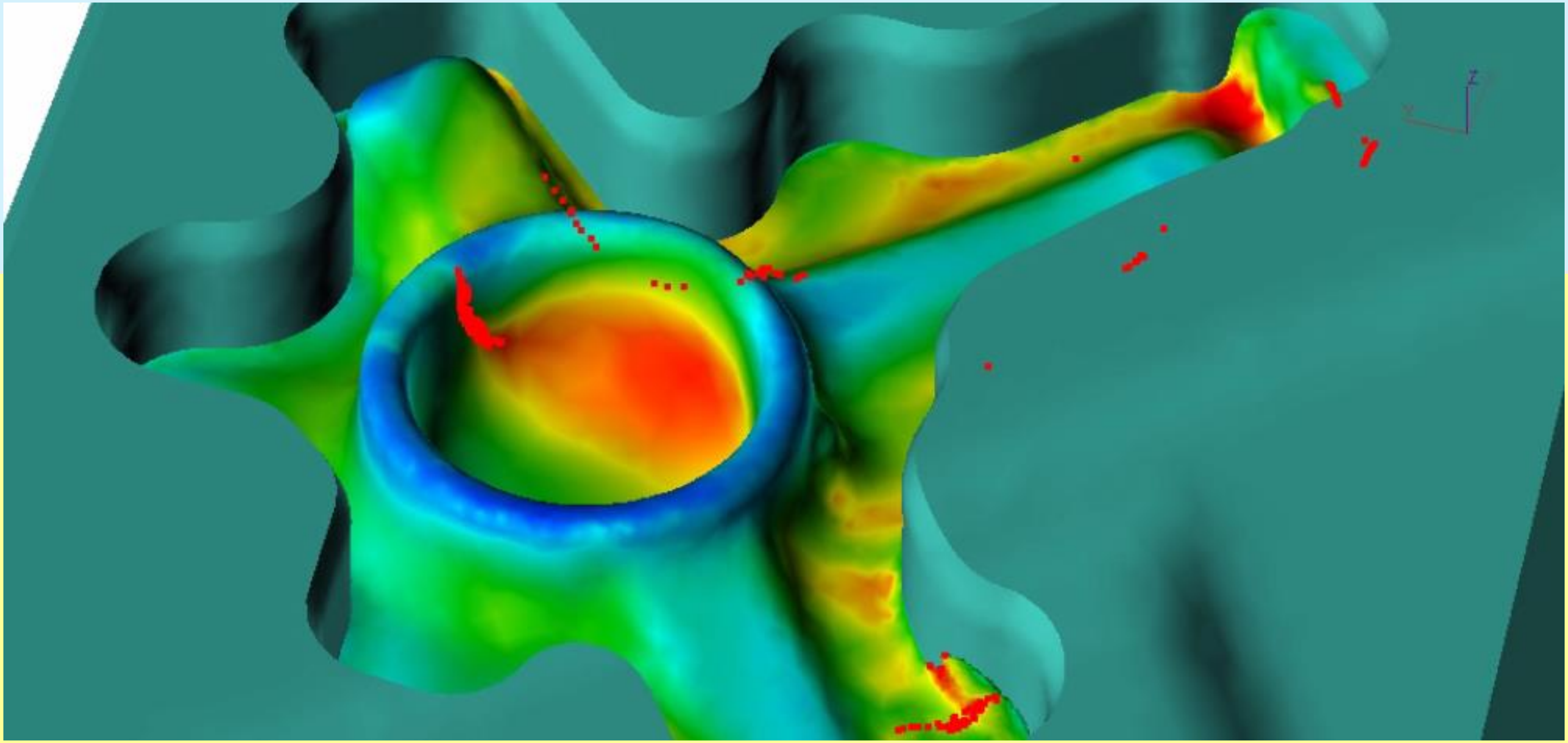
Advantages:

-User's subroutine are accepted by QForm 7 just as text files with program codes
-No compiler required
-Fast as the main program code
-Results of UDF appear in a line with standard variables and fields
-Free software

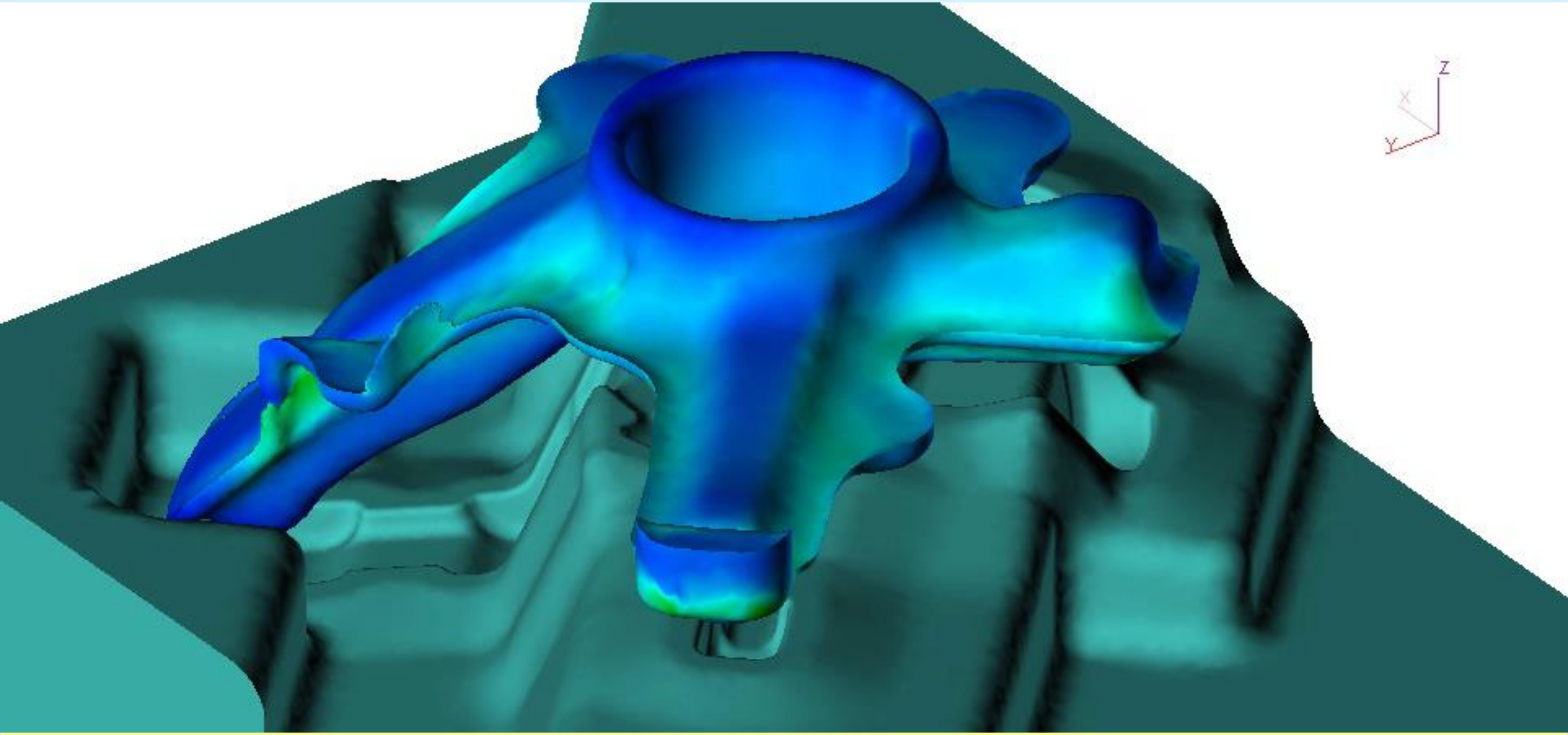
# QForm 7 possesses full range of methods and models for R&D

- **Mechanically and thermally and microstructurally coupled simulation**
- Explicit and implicit solvers
- Thermo-elastic-plastic simulation
- Material removal during forming and between operations
- Distortion  and residual stress analysis due to thermal shrinking/expansion
- Multi-body unilateral contact (bimetallic billets and assembled dies)
- Load or gravity controlled tools (manipulators, idle rolls, mandrels etc)
- Dual mesh method for incremental forming processes

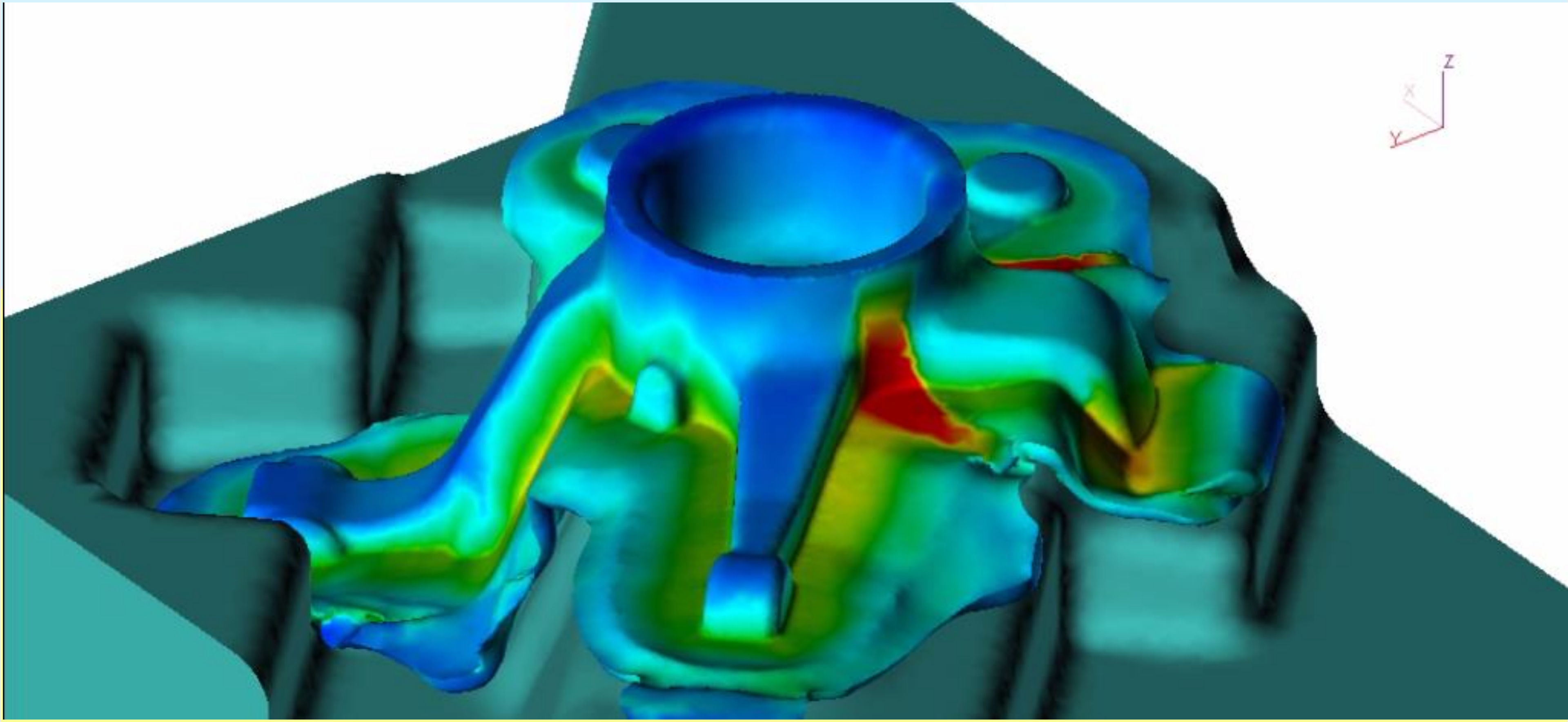
## Advanced mesh generation method that easily works folds and laps and never crashes



## Tracking  folds and laps from blow to blow

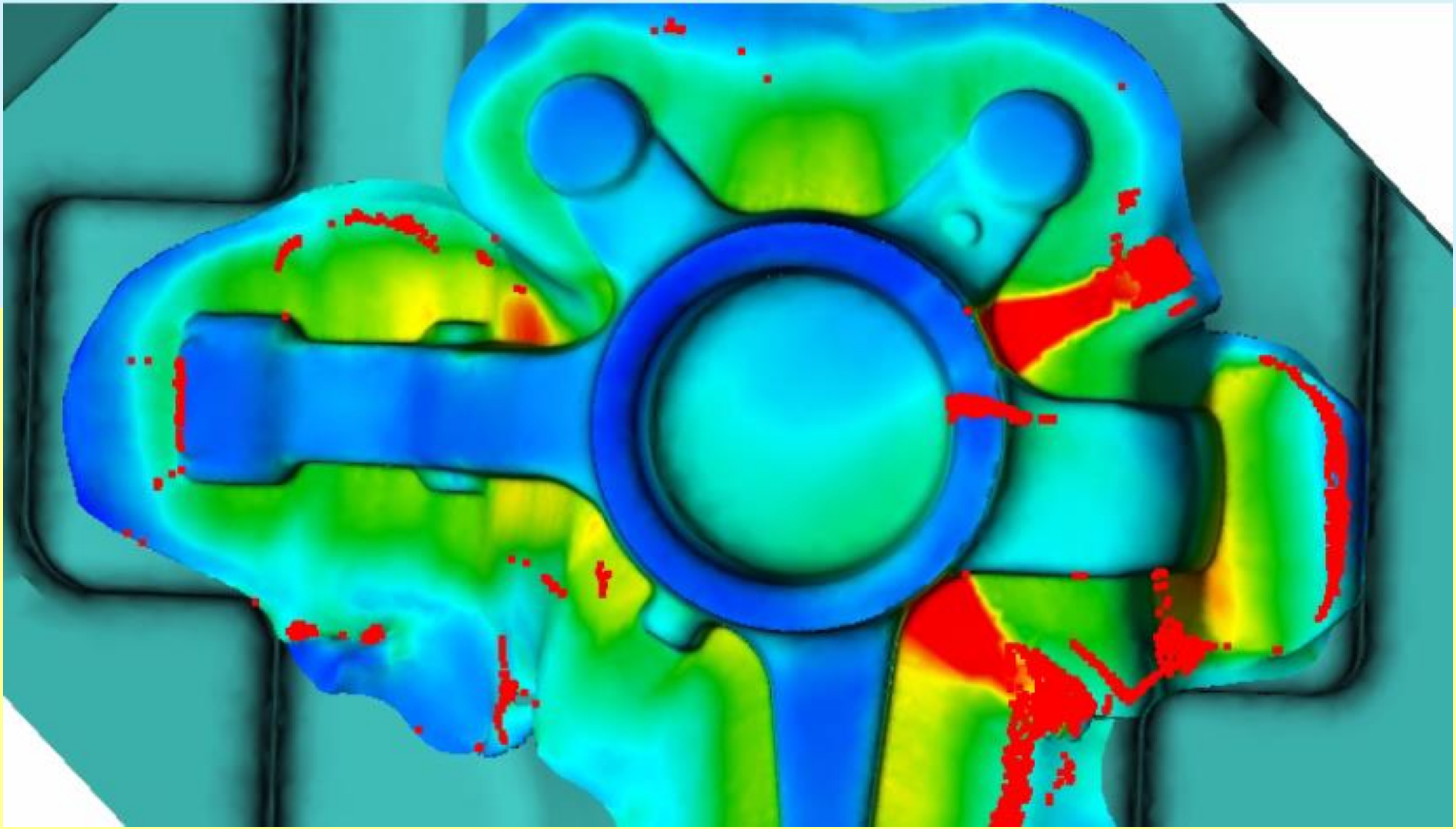


# Tracking  folds and laps from blow to blow

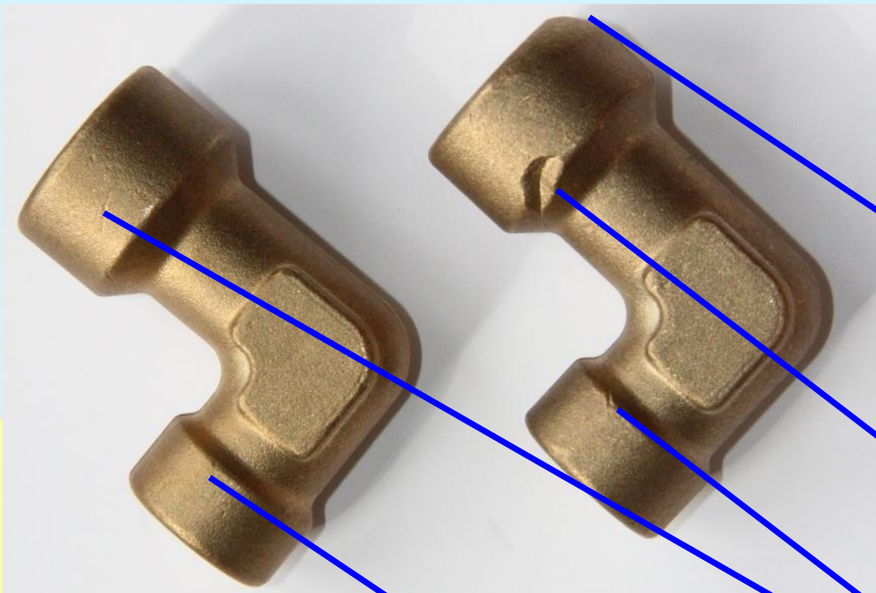


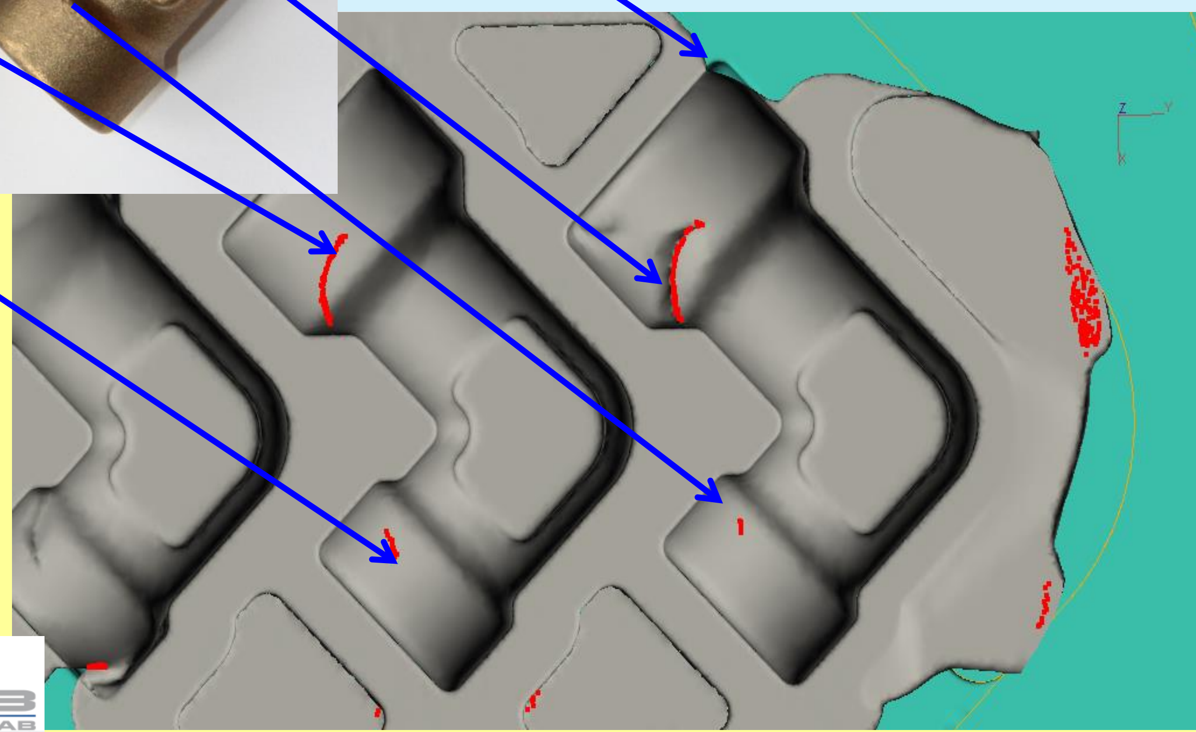
QForm UK

# Tracking folds and laps from blow to blow



# Best performance in predicting forging defects





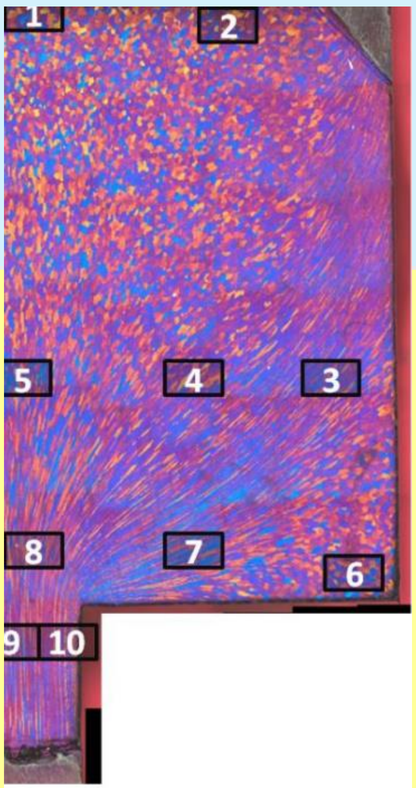
With kind permission «Holsby Metall AB», Sweden

HMAB HOLSBY METALL AB

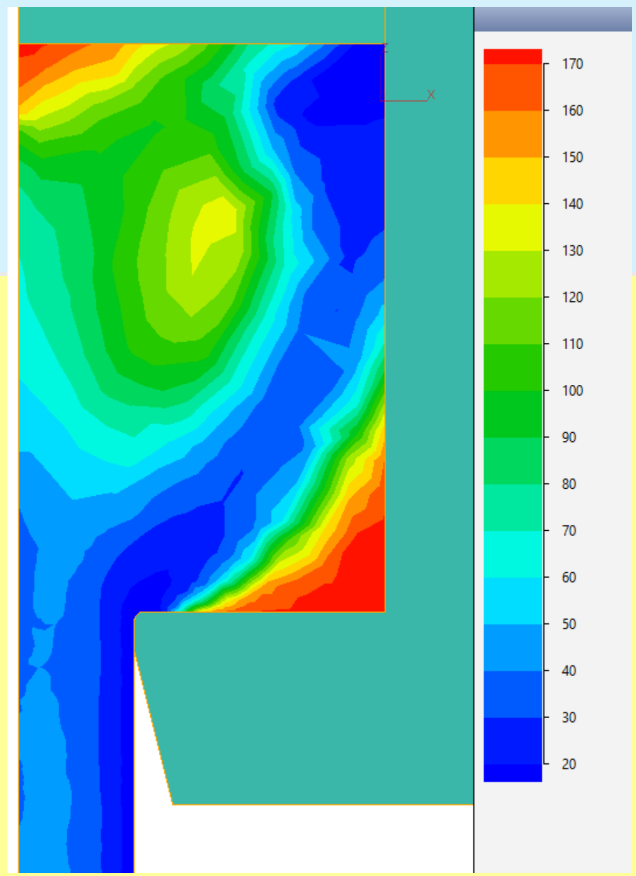
QForm UK

# Variety of material models has been already developed in QForm 7 environment and they can be shared within community for use and modifications

## Example: Microstructural modelling of aluminium alloy AA6060 (extrusion)




**Grains thickness (mkm)**




**Grain length (mkm)**

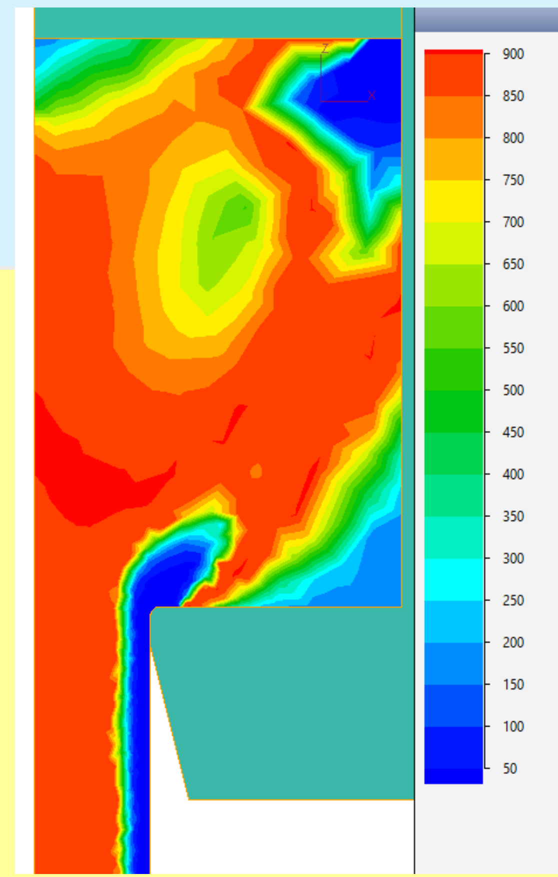
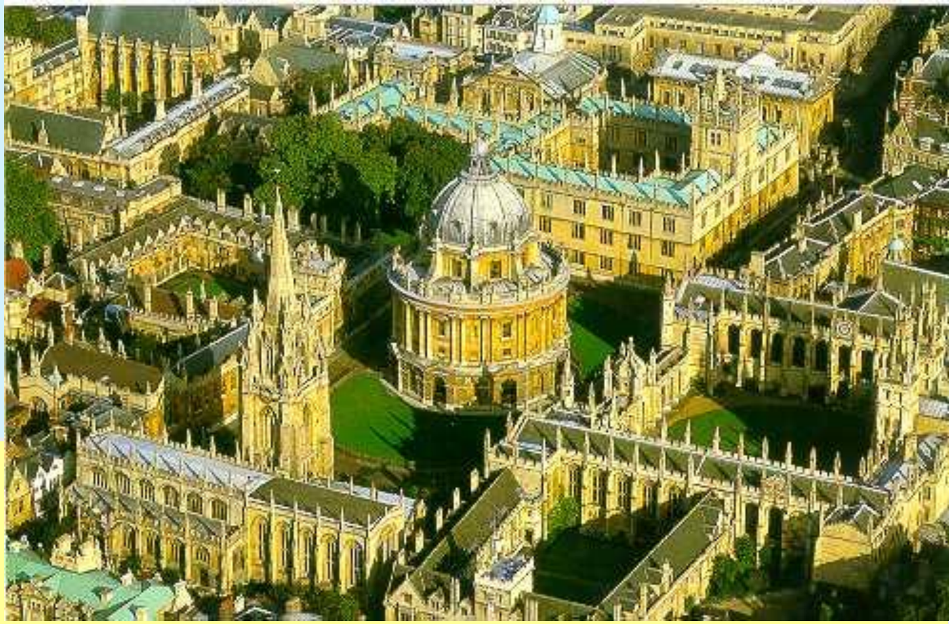



Photo and experiments courtesy of Dr. A. Segatori, Bologna University

QForm UK

**The next QForm 7 simulation seminar is on 23-24 of October 2014 in Oxford**



**Details on www.qform3d.co.uk**

# Thank you!

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***Nikolay Biba***, *QForm UK, MICAS Simulations Ltd.,Oxford, UK, micas@qform3d.co.uk, +441865775412*