Quantor Form

QFORM2D/3D

QForm3D

Heat treatment and microstructural simulation

Dr. Nikolay Biba, MICAS Simulations Ltd.

In collaboration with GMS Bernau (Germany)

Presented on 30.09.2010 at Mettis Aerospace during the IMfT workshop

IMfT

Quantor Form

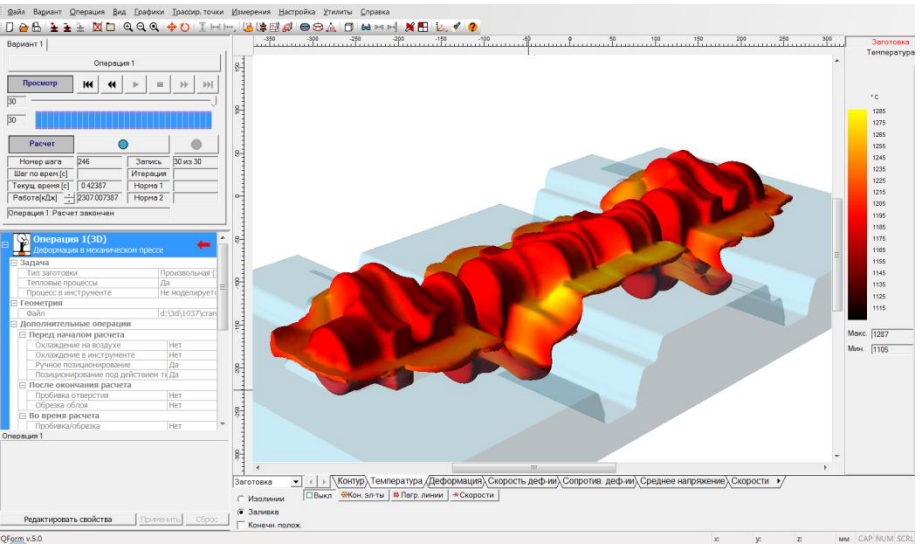
QFORM2D/3D

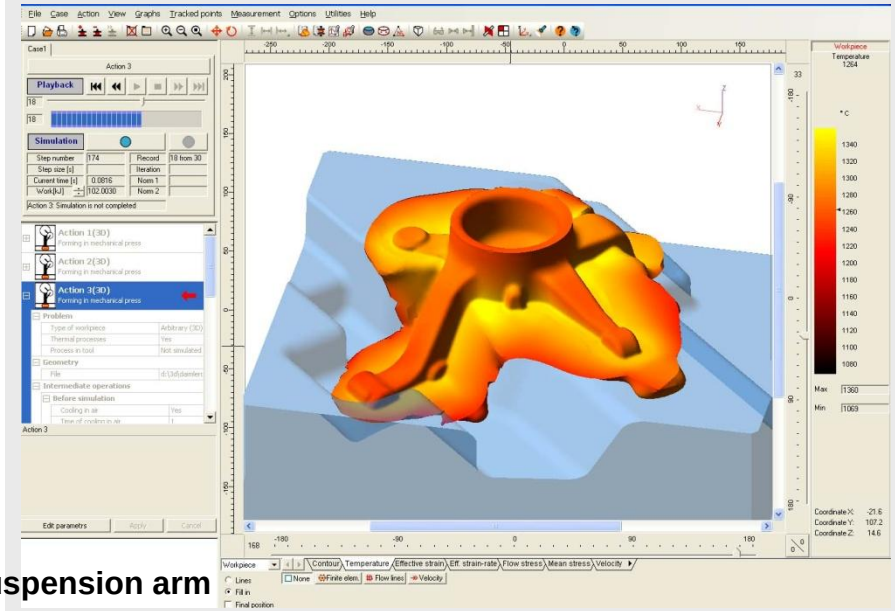
QForm

Unique user-friendly interface

No limits for complexity of simulation job – full 64-bit application, running in parallel on up to 8 CPUs

Versatile simulation tool: simulates all kinds of metal forming and related processes



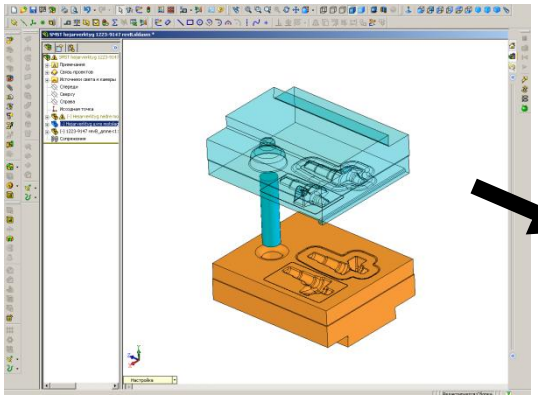


Examples of automotive parts simulations: crankshaft and suspension arm

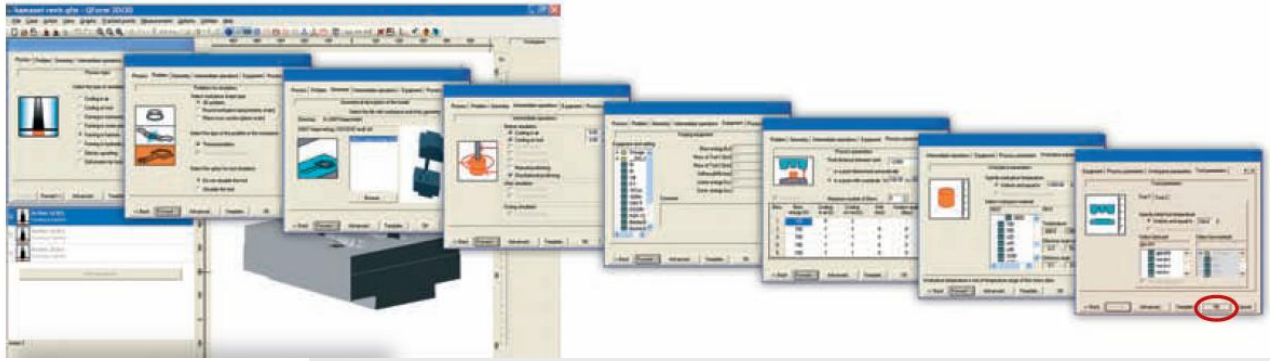
Quantor Form

QFORM2D/3D

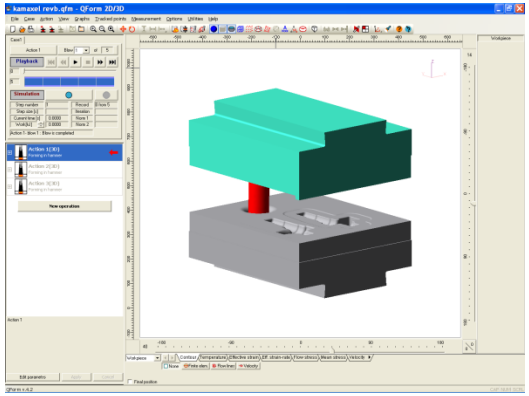
Unique user-friendly interface excludes the needs for special training



1) CAD model

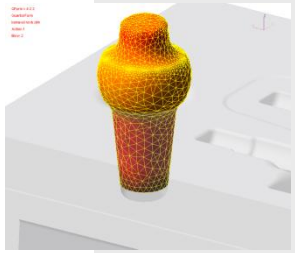


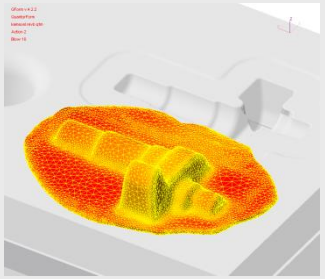
2) Setup project

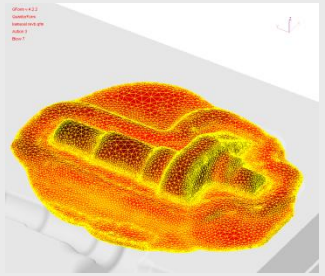


3) Run simulation

4) Results of Hammer forging simulation





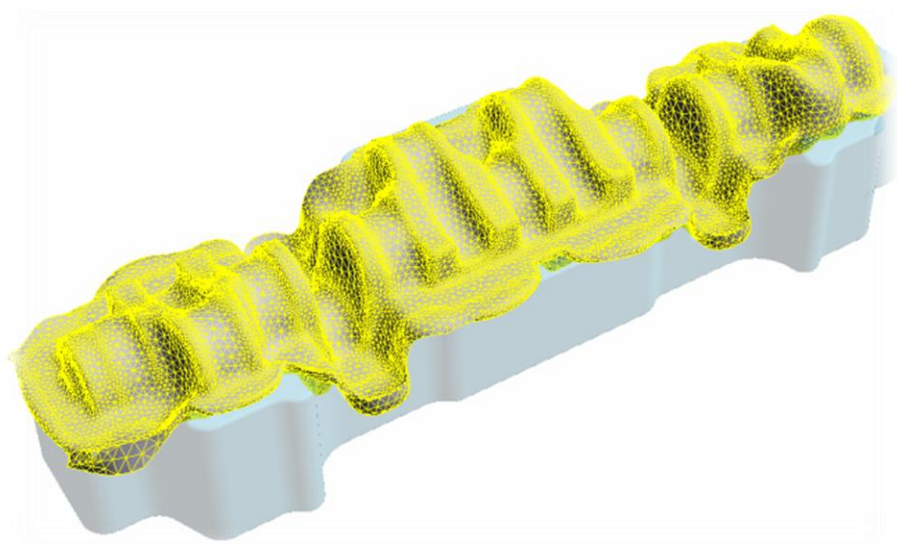


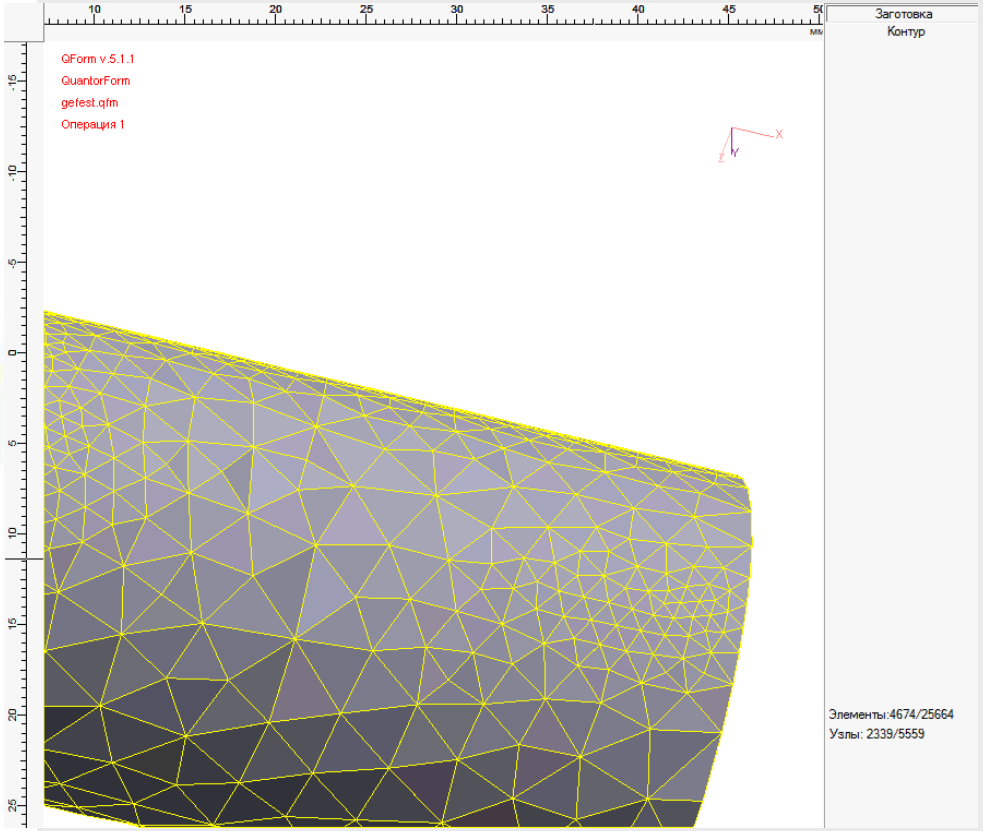
Quantor Form

QFORM2D/3D

Automated simulation without any user interference

Automated mesh generation for forging the products of any shape and any problem size



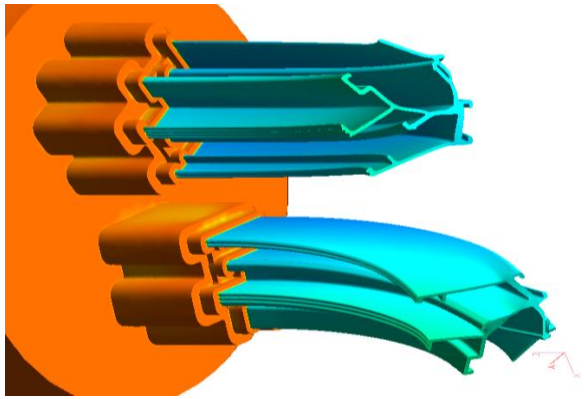


Automated sophisticated mesh generation in QForm: mesh density is precisely tuned to die shape and material flow pattern at any stage of the process

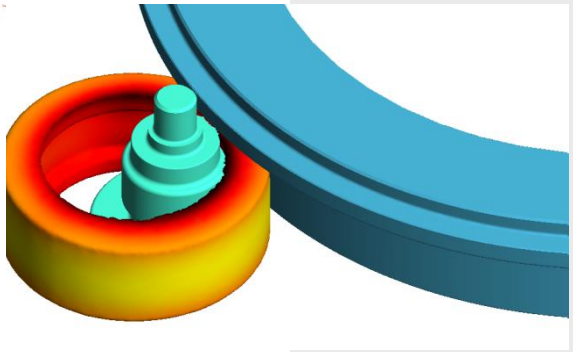
Quantor Form

QFORM2D/3D

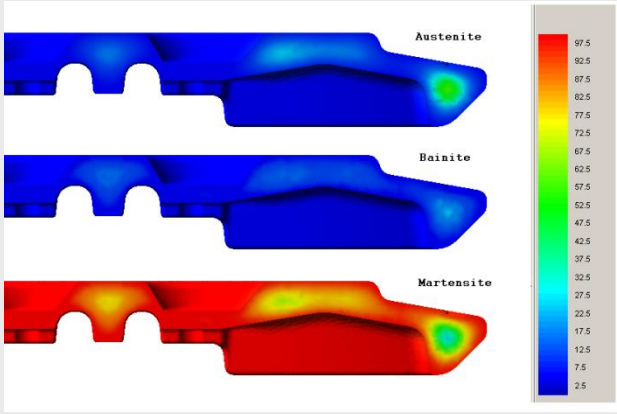
Versatile simulation tool : Simulation of all kinds of metal forming processes



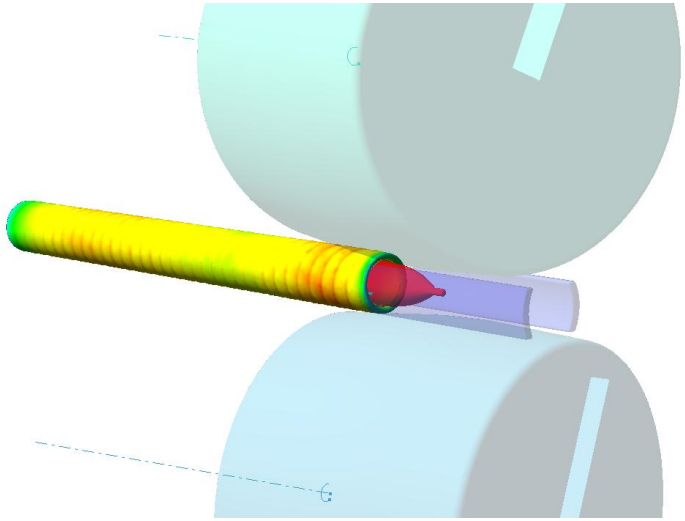
Profile extrusion



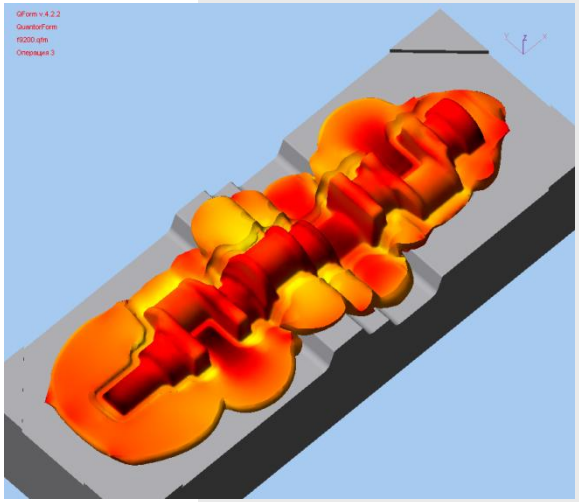
Ring rolling

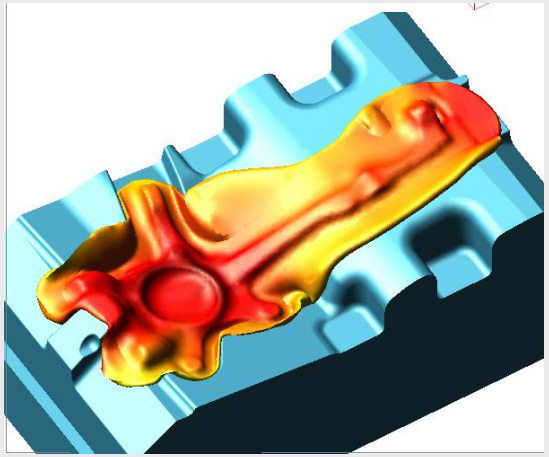


Heat treatment
and microstructure prediction



Helical rolling

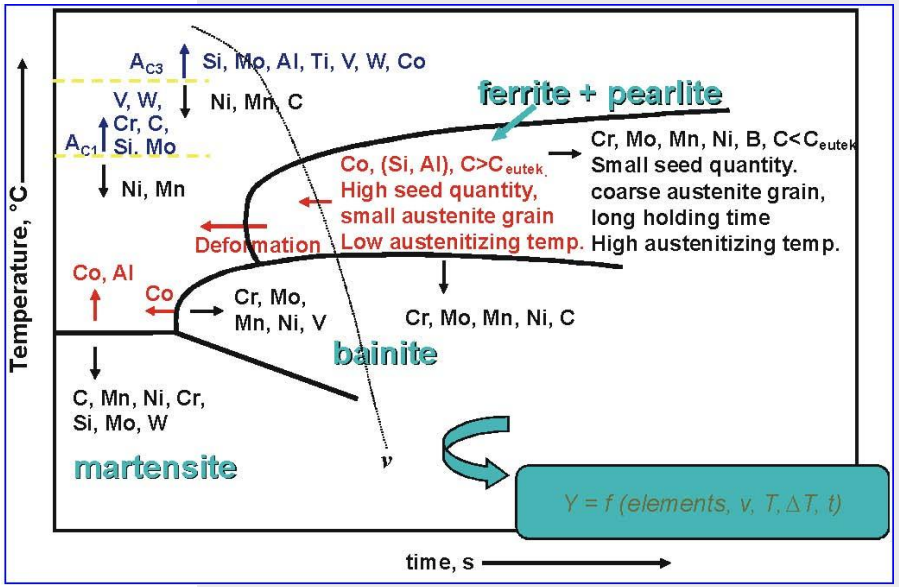




Closed die forging

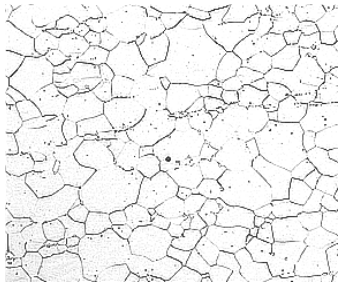
Schematic TTT-Diagram

Alloying elements significantly influence the shape of the phase boundaries on TTT-diagram

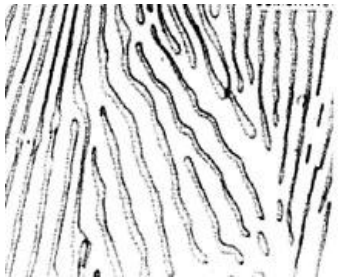


Samples of the phases predicted by QForm-Heat Treatment module

Ferrite



Perlite



Bainite

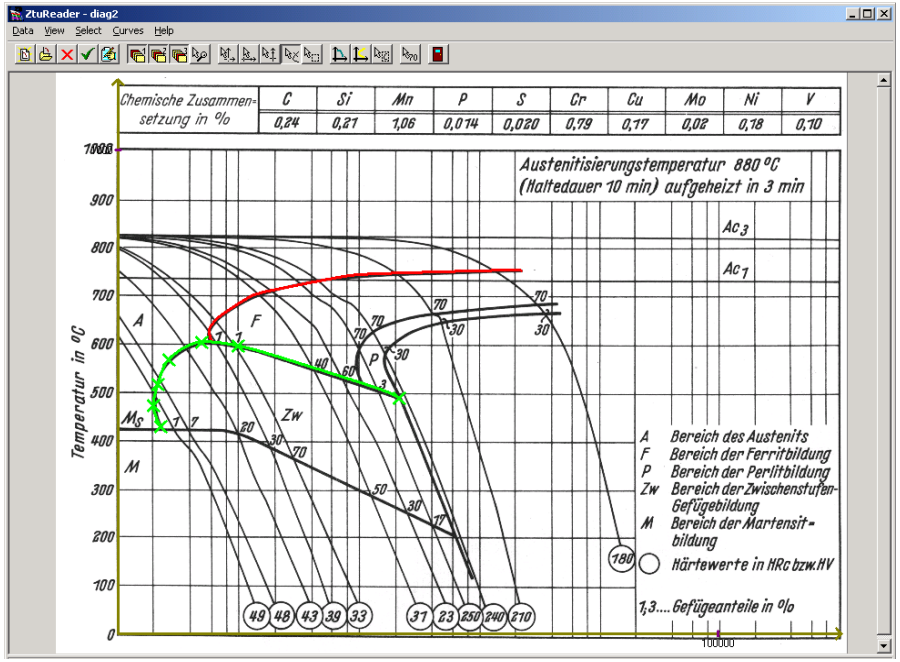
Martensite

Quantor Form

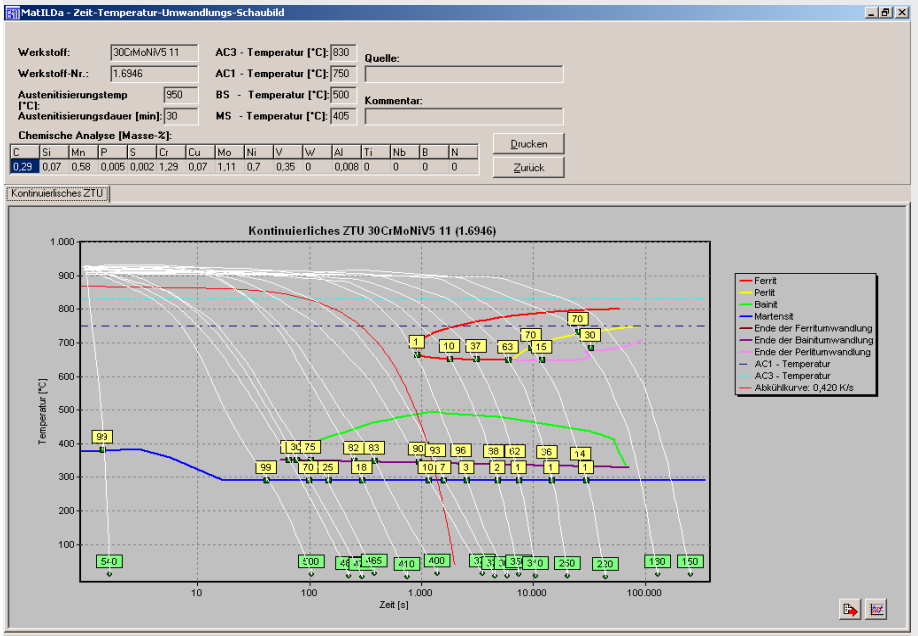
QFORM2D/3D

Experimental analysis of phase transformation phenomenon*

Digitizing actual TTT-diagrams for different variations of chemical composition



Creating numerical diagrams suitable for interpolation



*) by GMS Bernau

Steel groups and variation of their chemical compositions available for simulation*

	Gr. 1	Gr. 2	Gr. 3	Gr. 4	Gr. 5	Gr. 6	Gr. 11	Gr. 12	Gr. 13	Gr. 14	Gr. 15	Gr. 16	Gr. 17	Gr. 18	Gr. 19	Gr. 20
C	0.003 – 0.013	0.04 – 0.22	0.221 – 0.83	0.11 – 0.20	0.14 – 0.22	0.03 – 0.22	0.10 – 0.70	0.13 – 0.65	0.05 – 0.50	0.12 – 0.26	0.47 – 0.62	0.08 – 0.40	0.18 – 0.42	0.17 – 0.40	0.36 – 0.44	0.15 – 0.39
Si	<= 0.02	<= 1.40	<= 0.40	<= 0.50	<= 0.04	<= 1.40	<= 0.50	<= 0.40	<= 0.45	<= 0.45	<= 0.40	<= 0.50	<= 0.40	<= 0.40	<= 0.50	0.21 – 0.40
Mn	0.10 – 0.26	0.20 – 1.60	0.30 – 1.50	0.60 – 1.80	0.70 – 1.40	0.20 – 1.80	0.40 – 1.40	0.30 – 1.20	0.70 – 1.90	0.50 – 0.80	0.70 – 1.10	0.40 – 1.15	0.15 – 0.60	0.30 – 0.80	1.50 – 1.70	0.70 – 1.50
Cr	< 0.20	<= 0.40	<= 0.40	0.50 – 1.50	0.30 – 1.30	<= 0.40	0.24 – 1.30	0.90 – 1.50	<= 0.30	<= 0.30	0.90 – 1.20	0.30 – 1.50	1.00 – 2.00	0.90 – 1.40	0.10 – 0.25	<= 0.25
Cu	< 0.20	<= 0.30	<= 0.20	<= 0.21	<= 0.40	<= 0.30	<= 0.30	<= 0.25	<= 0.30	<= 0.30	<= 0.30	<= 0.40	< 0.25	< 0.20	< 0.20	< 0.20
Mo	< 0.01	<= 0.06	<= 0.06	<= 0.05	0.12 – 0.40	<= 0.06	<= 0.60	0.10 – 0.36	<= 0.05	0.20 – 0.35	<= 0.30	0.30 – 0.80	0.30 – 0.60	0.60 – 1.20	<= 0.05	<= 0.02
Ni	< 0.10	<= 0.30	<= 0.20	<= 0.40	0.20 – 0.80	<= 0.30	<= 0.30	<= 0.25	<= 0.30	<= 0.30	<= 0.20	<= 0.40	2.5 – 4.0	0.20 – 0.80	<= 0.20	<= 0.20
V	< 0.01	<= 0.10	<= 0.10	<= 0.30	<= 0.06	<= 0.18	< 0.02	< 0.02	<= 0.20	< 0.02	< 0.02	< 0.02	<= 0.20	0.25 – 0.35	0.08 – 0.10	< 0.01
Al	0.007 – 0.064	<= 0.070	<= 0.037	<= 0.300	<= 0.060	<= 0.070	<= 0.035	<= 0.035	< 0.050	< 0.050	< 0.050	< 0.050	<= 0.050	< 0.20	< 0.20	<= 0.060
Ti	0.001 – 0.081	<= 0.08	<= 0.06	<= 0.01	<= 0.01	<= 0.08	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Nb	<= 0.036	<= 0.05	< 0.02	< 0.02	< 0.02	<= 0.15	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.05
B	< 0.0001	<= 0.0005	< 0.0001	< 0.0001	< 0.0001	< 0.0001	<= 0.0005	<= 0.0005	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	<= 0.0050
N	<= 0.007	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
P	< 0.040	< 0.040	< 0.040	< 0.040	< 0.040	< 0.040	<= 0.040	<= 0.035	< 0.040	< 0.040	< 0.040	< 0.040	<= 0.005	<= 0.030	< 0.040	< 0.040
S	< 0.040	< 0.040	< 0.040	< 0.040	< 0.040	< 0.040	<= 0.035	<= 0.035	< 0.040	< 0.040	< 0.040	< 0.040	<= 0.001	<= 0.035	< 0.040	< 0.040
Sn																
Ca																
H_2																

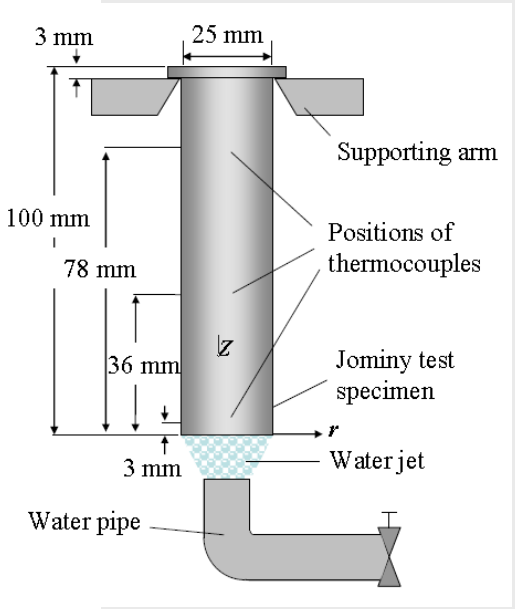
	used in calculation of phase transformation and their starting temperatures
	for some materials used in calculation of starting temperatures for phase transformation
	currently not used MatILDa transformation

*) by GMS Bernau

Simulation of Jomini test

Carbon steel
Composition, %

(C 0.60)
(Si 0.50)
(Mn 0.8)
(Cr 1.00)
(Cu 0.2)
(Mo 0.02)
(Ni 0.10)
(Al 0.02)
(S 0.02)
(P 0.01)
(B 0.00)



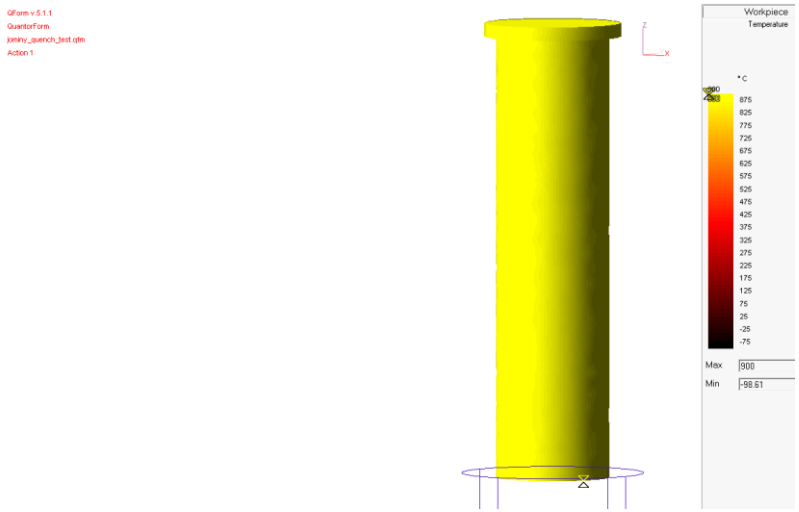
a b

Typical scheme of the experiment (a) and photo of the equipment (b)

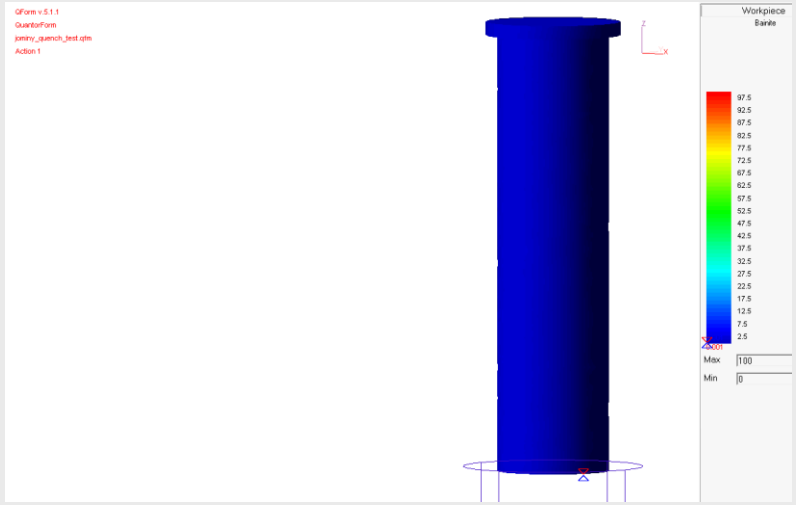
from A. Güzel, A. Jäger, N. Ben Khalifa, A. E. Tekkaya. International Conference on Extrusion and Benchmark (ICEB), Dortmund 2009, Germany

Simulation of Jomini test

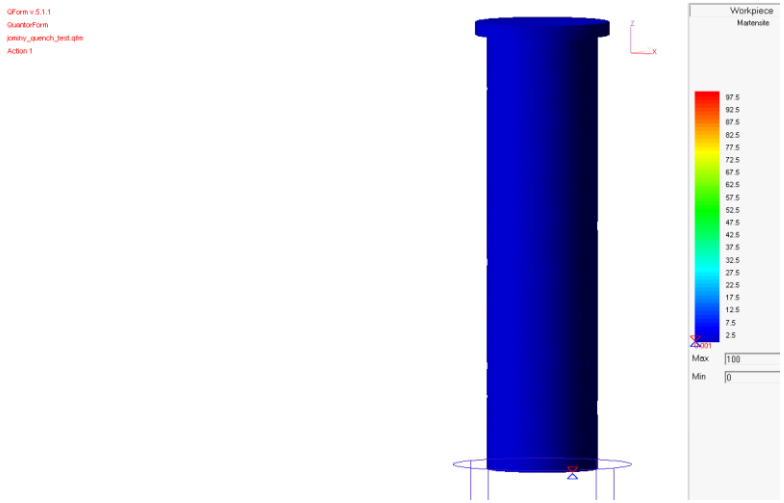
Temperature



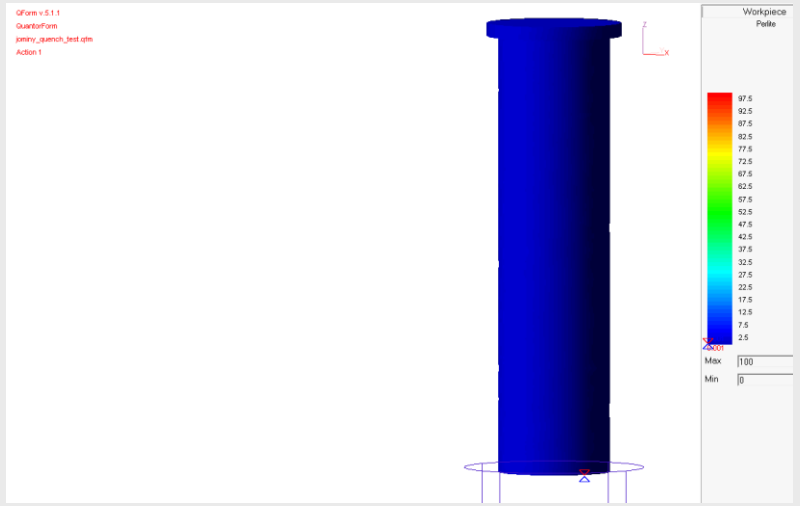
Bainite



Martensite



Perlite

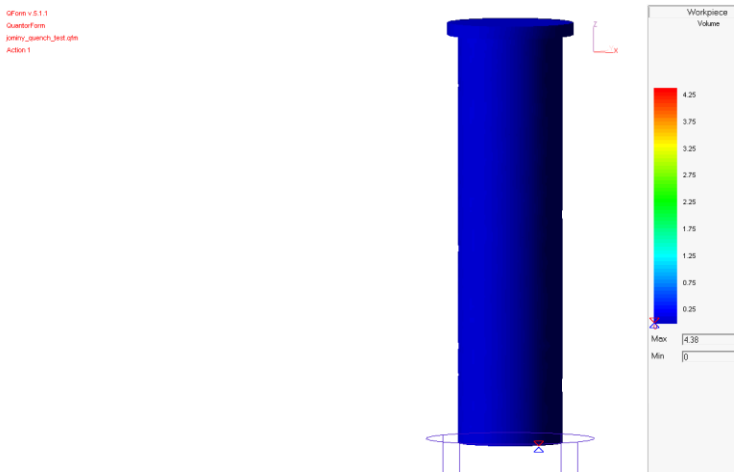


Quantor Form

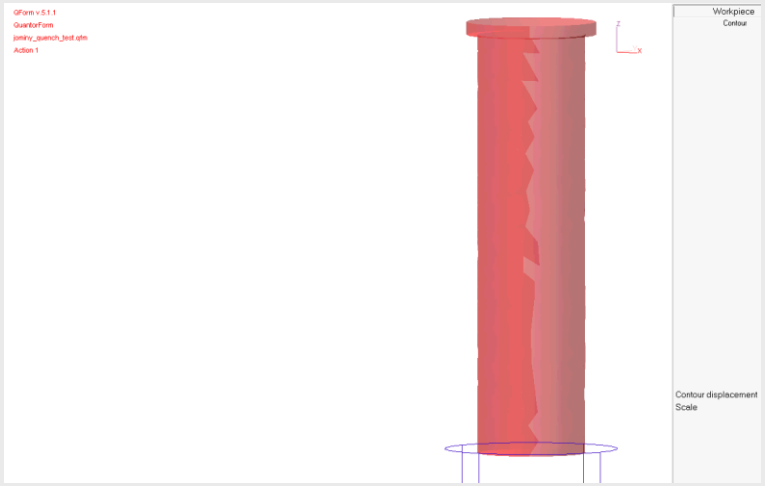
QFORM2D/3D

Hardness, thermal stresses, thermal distortion in Jomini test simulation

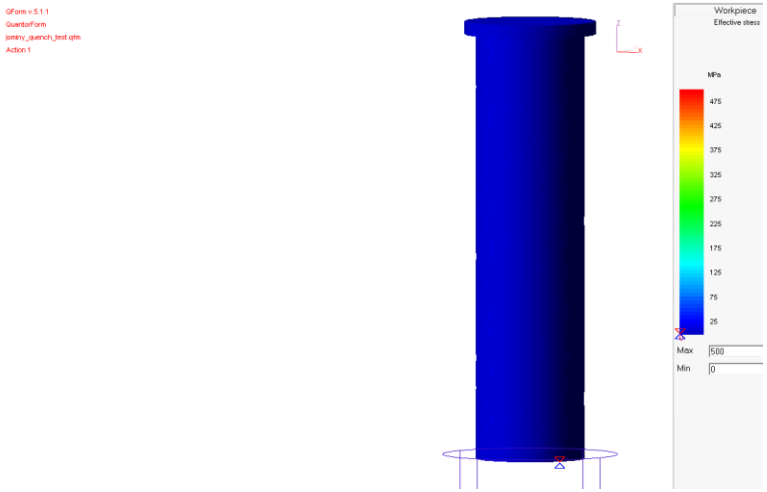
Volume change



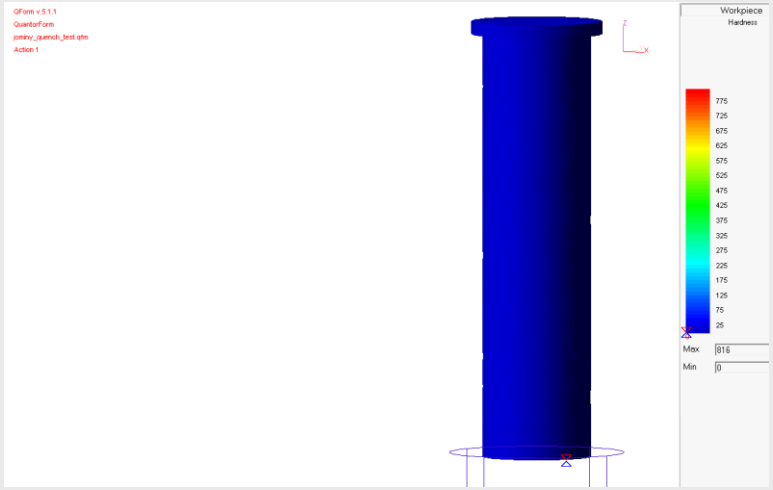
Deformed contour (scale 50:1)



Effective stress



Hardness

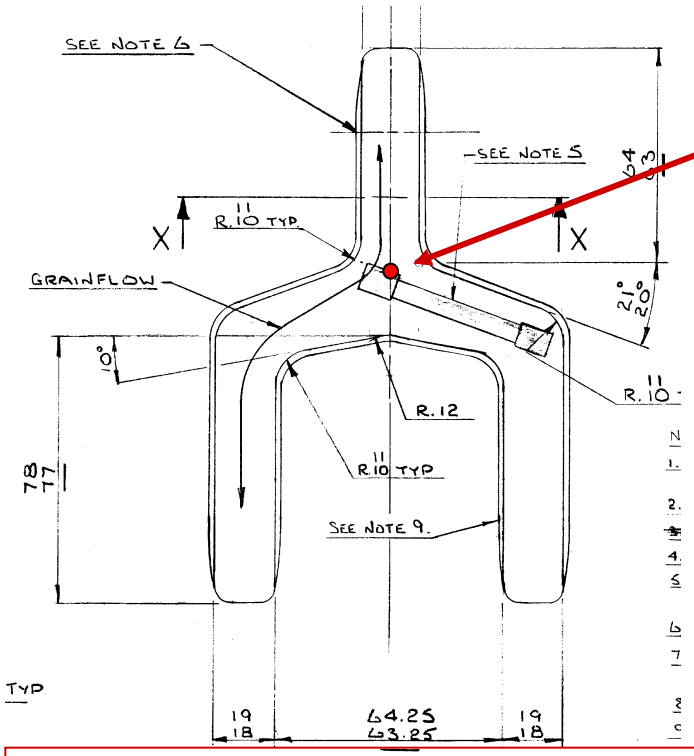


Case Study No 1

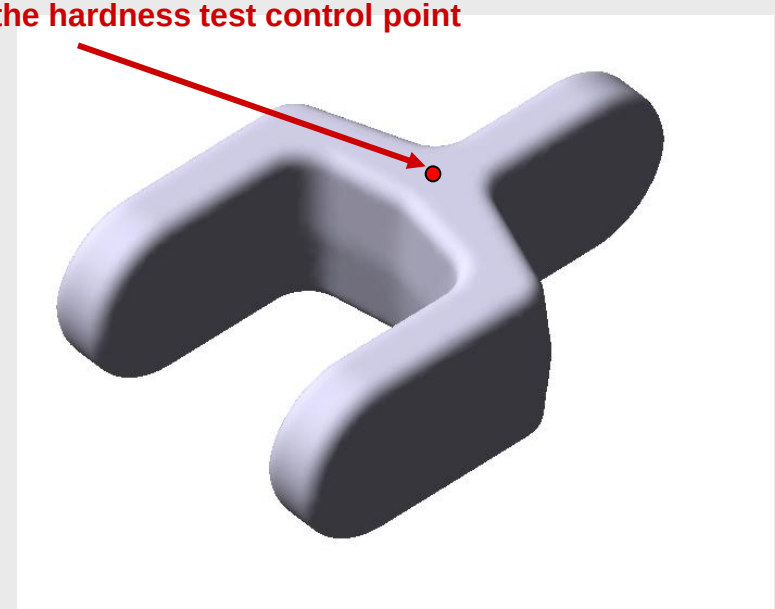
Heat Treatment Simulation of a Steel Forged Part

In collaboration with Mettis Aerospace (UK)

Drawing and general view of the forged part for heat treatment



Location of the hardness test control point



Material NiCrMo Steel aerospace standard BS S154 used for structural applications

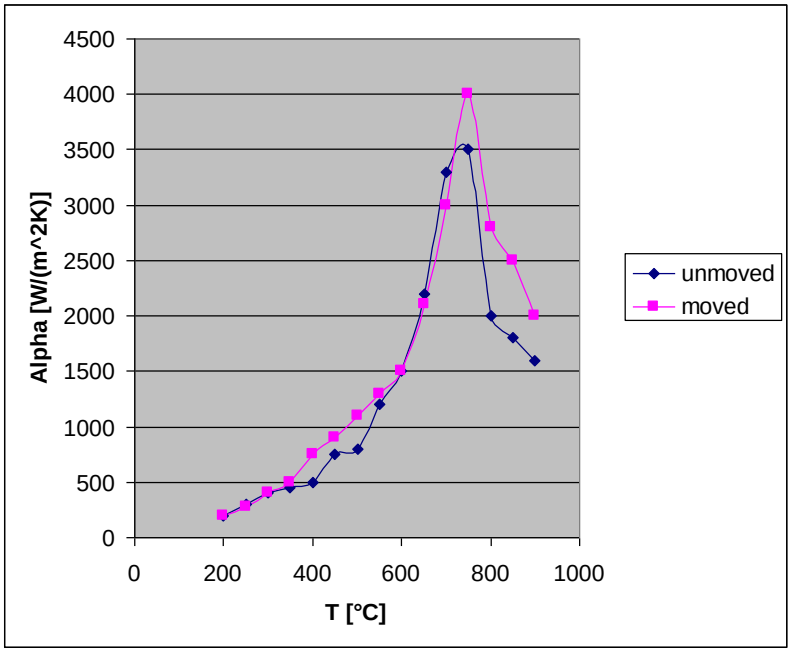
Typical Chemical Analysis:

	C %	Si%	Mn%	Cr%	Mo%	Ni%	
min	0.27	0.15	0.45	0.50	0.45	2.30	***Lower limit***
Medium	0.3	0.25	0.6	0.7	0.5	2.5	*Medium level*
Max	0.35	0.35	0.70	0.80	0.65	2.80	***Upper limit***

Simulation of the forged part heat treatment

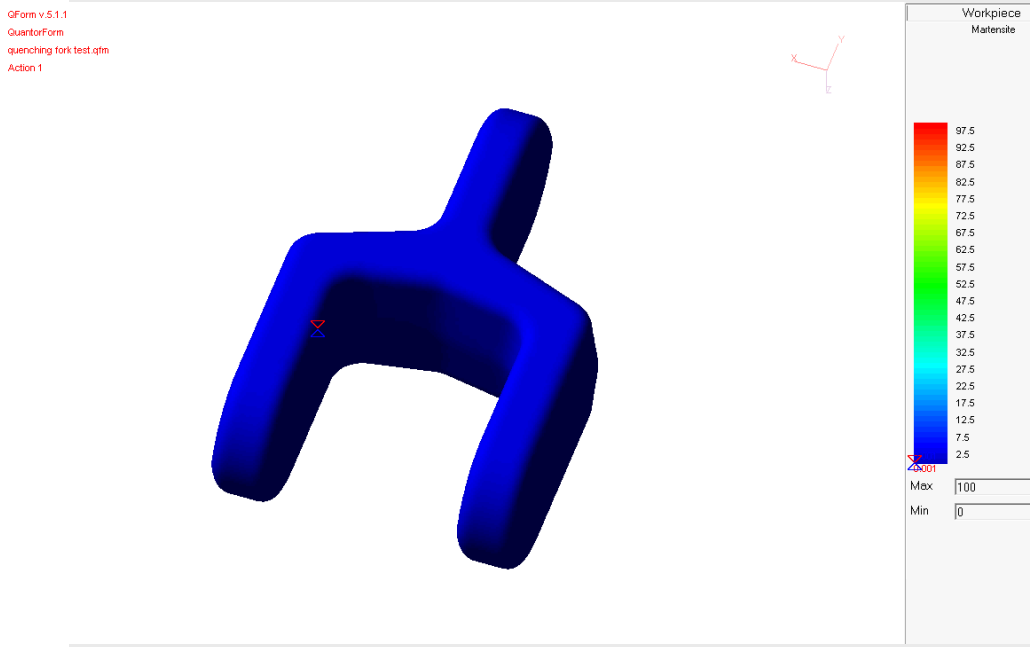
Heat treatment operations:

Hardening: 2-4 hours at 850C than oil quenched
Tempering: 3-6 hours at 630 C then air cooling to 20C

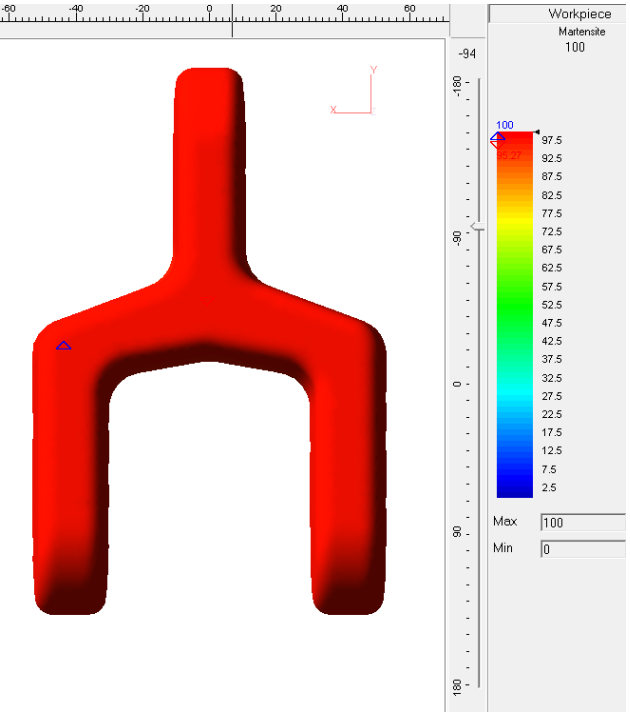


Heat transfer coefficient vs surface temperature when quenching in oil.

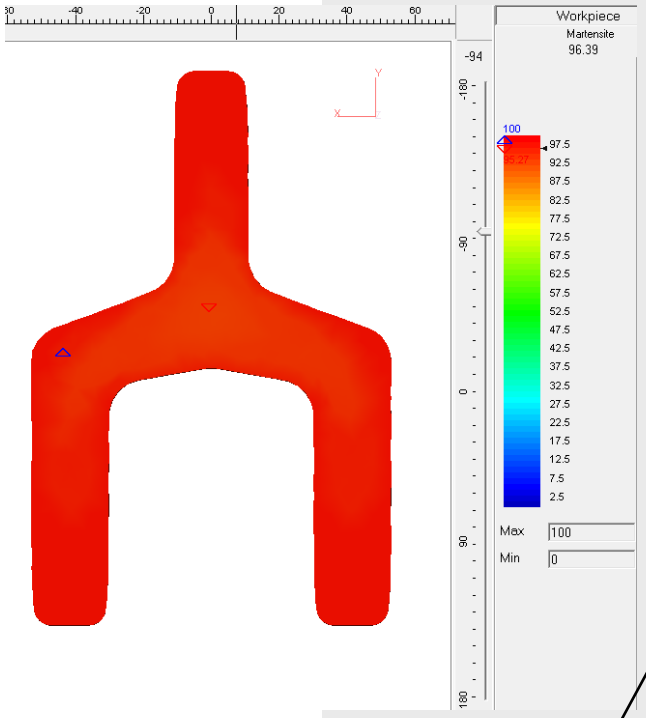
Formation of martensite over the surface during quenching



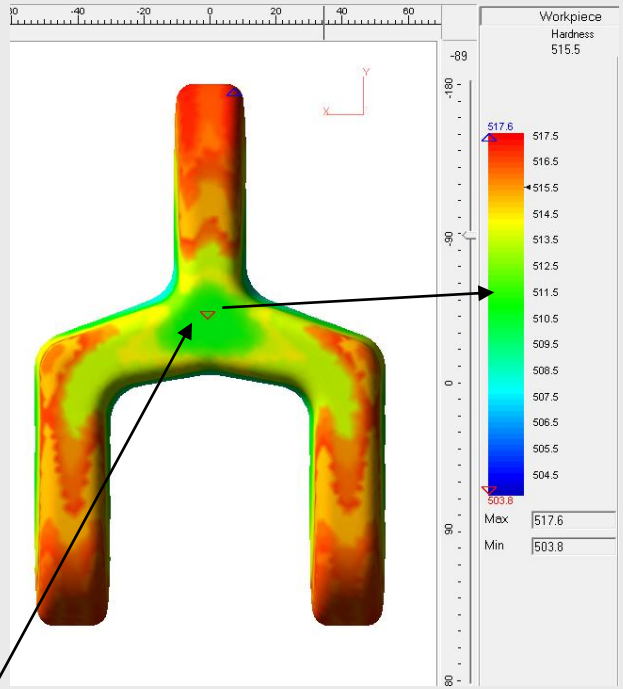
Medium content of alloying elements: results of simulation



Martensite on the surface



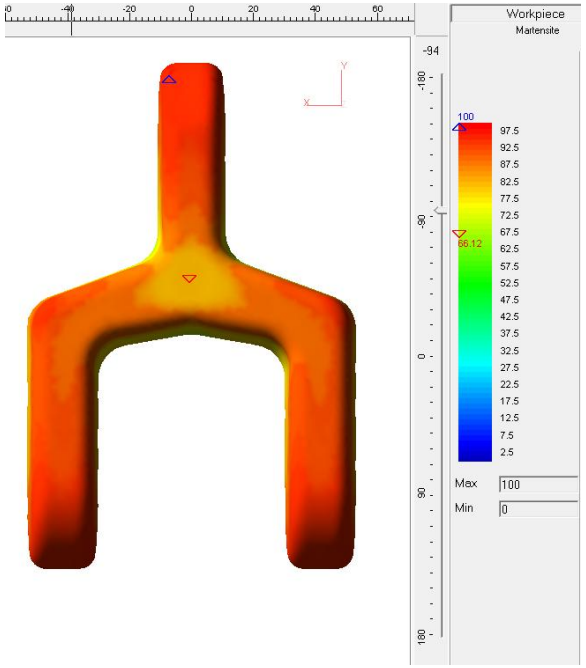
Martensite in crosscut



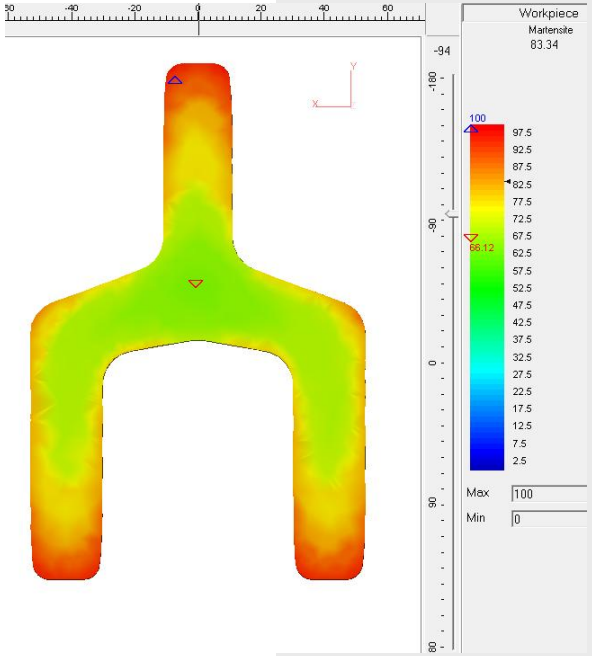
Hardness on surface

Hardness in control point is 511 HV

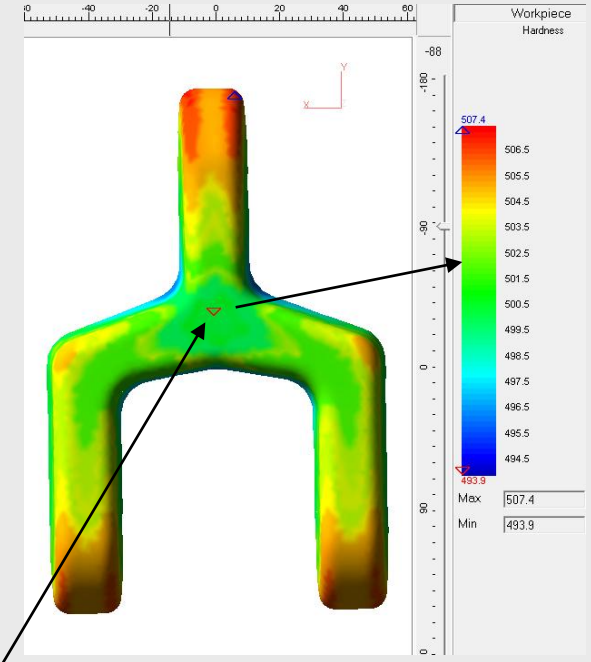
Lower content of alloying elements: results of simulation



Martensite on the surface



Martensite in crosscut



Hardness on surface

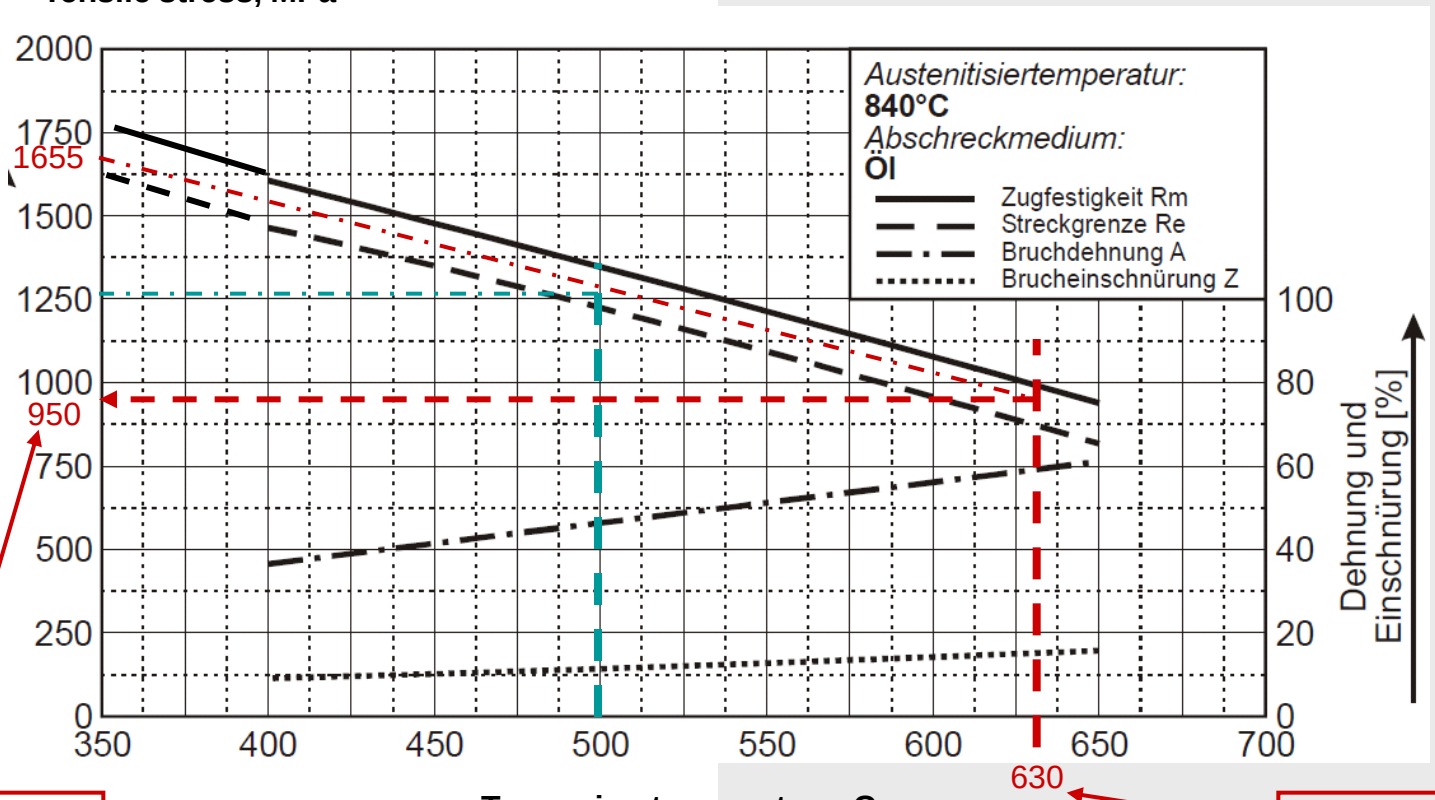
Hardness in control point is 500 HV

Parameters in the control point after quenching

Content of alloying elements	Martensite in centre (%)	Hardness, (HV)	Tensile stress (N/mm^2)
Upper	100	547	1810
Medium	95	511	1665
Lower	66	500	1630

Tempering of the steel: calculation of tensile stress for medium composition

Tensile stress after quenching



Tensile stress after tempering

Actual Tempering Temperature

Tempering diagram provides UTS after 4 hours at different temperatures

Parameters in the control point after quenching and tempering

Alloying elements content	Martensite in centre of the part (%)	Hardness, (HV)	Tensile stress (N/mm^2)	Tensile stress after tempering (N/mm^2)	Hardness after tempering, (HV)	Brinell hardness after tempering, (BHN)
Upper	100	547	1810	1080	340	323
Medium	95	511	1665	950	295	280
Lower	66	500	1630	920	290	276

Experimental results:

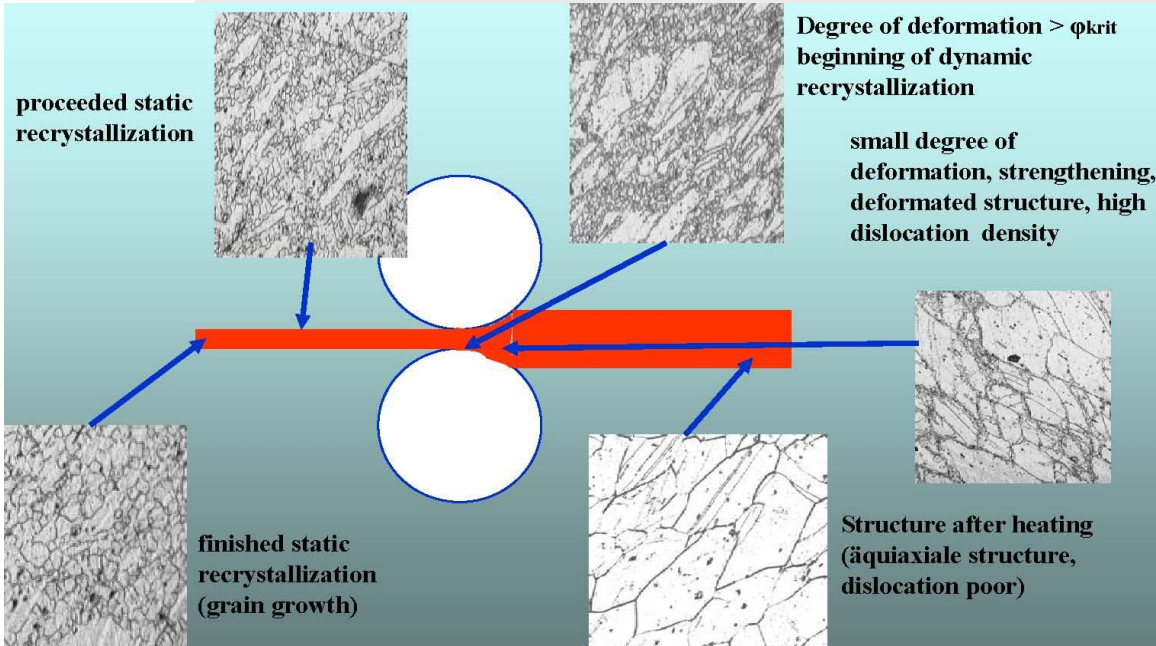
Hardness Brinell (BHN) 273-294, UTS 940 N/mm2

Simulation of microstructural evolution

QForm is integrated with model of metallurgical evolution developed by GMT Berlin (Germany)

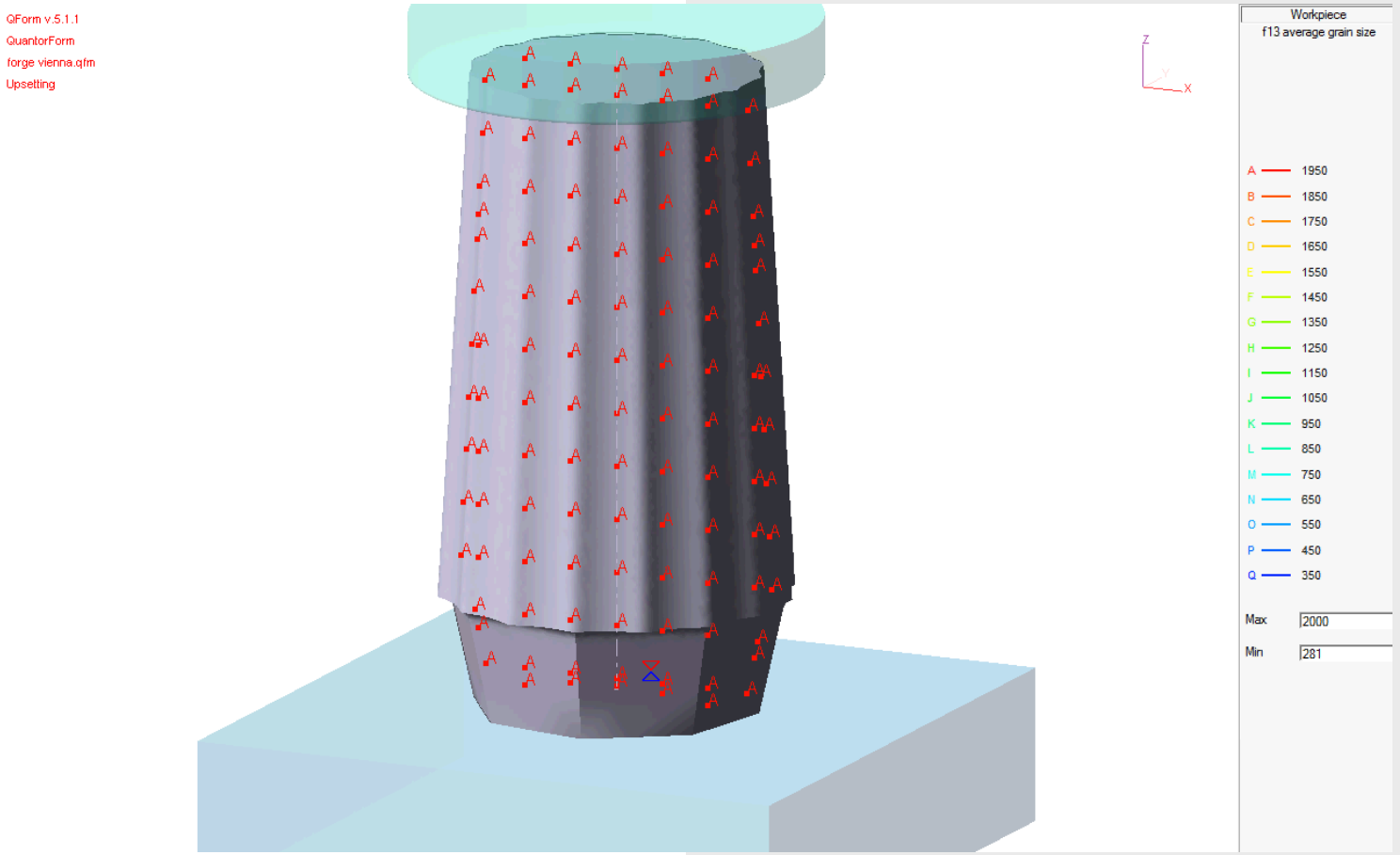
Module QForm-MS is based on Sellars model and simulates:

- Dynamic recrystallisation
- Static recrystallisation
- Grain growth



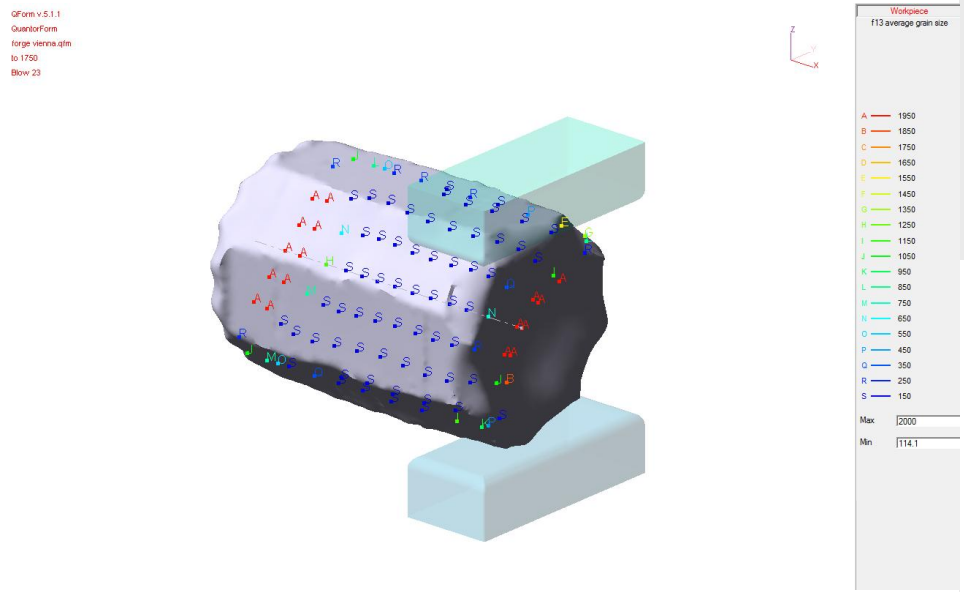
Open die forging simulation

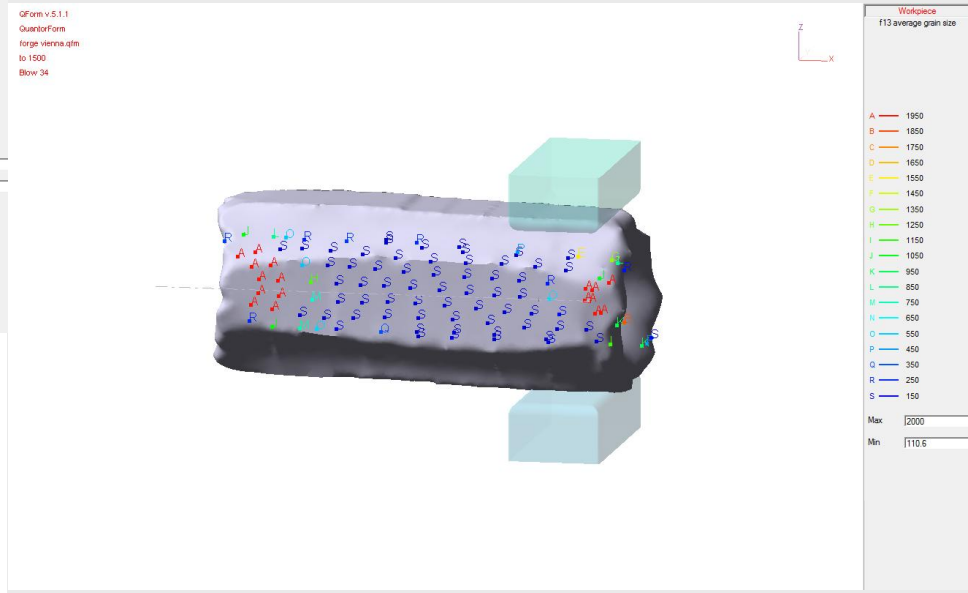
Steel 18NiCrMo7. Initial grain size from casting 2000 microns
Ingot 50 ton. Upsetting operation



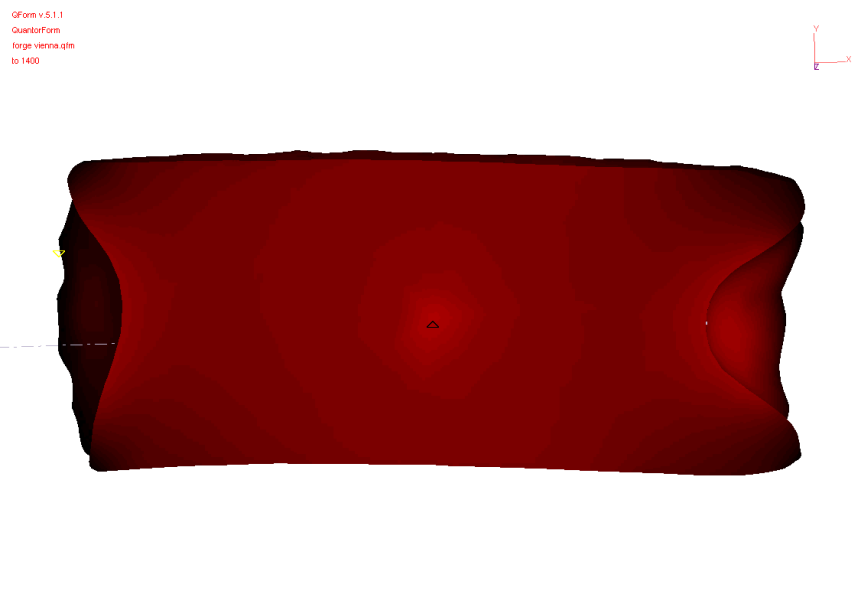
Open die forging simulation

Grain distribution after several passes





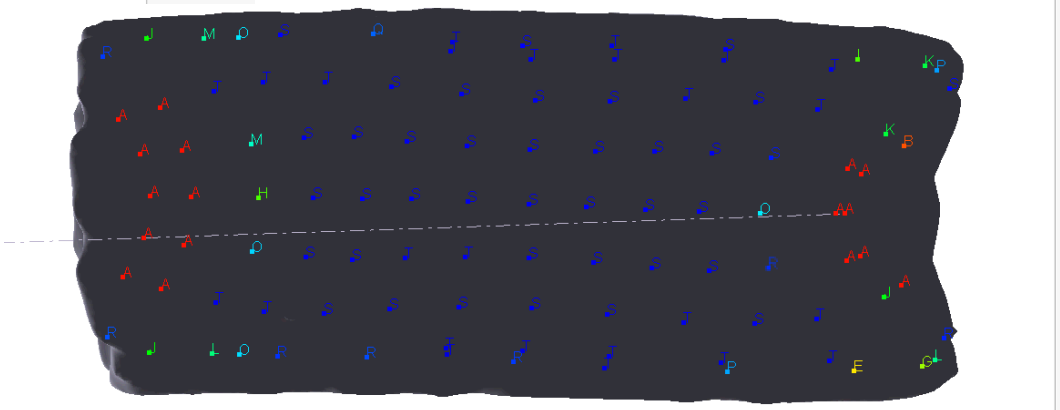
Open die forging simulation



Grain size during the ingot reheat. Time 15 hours

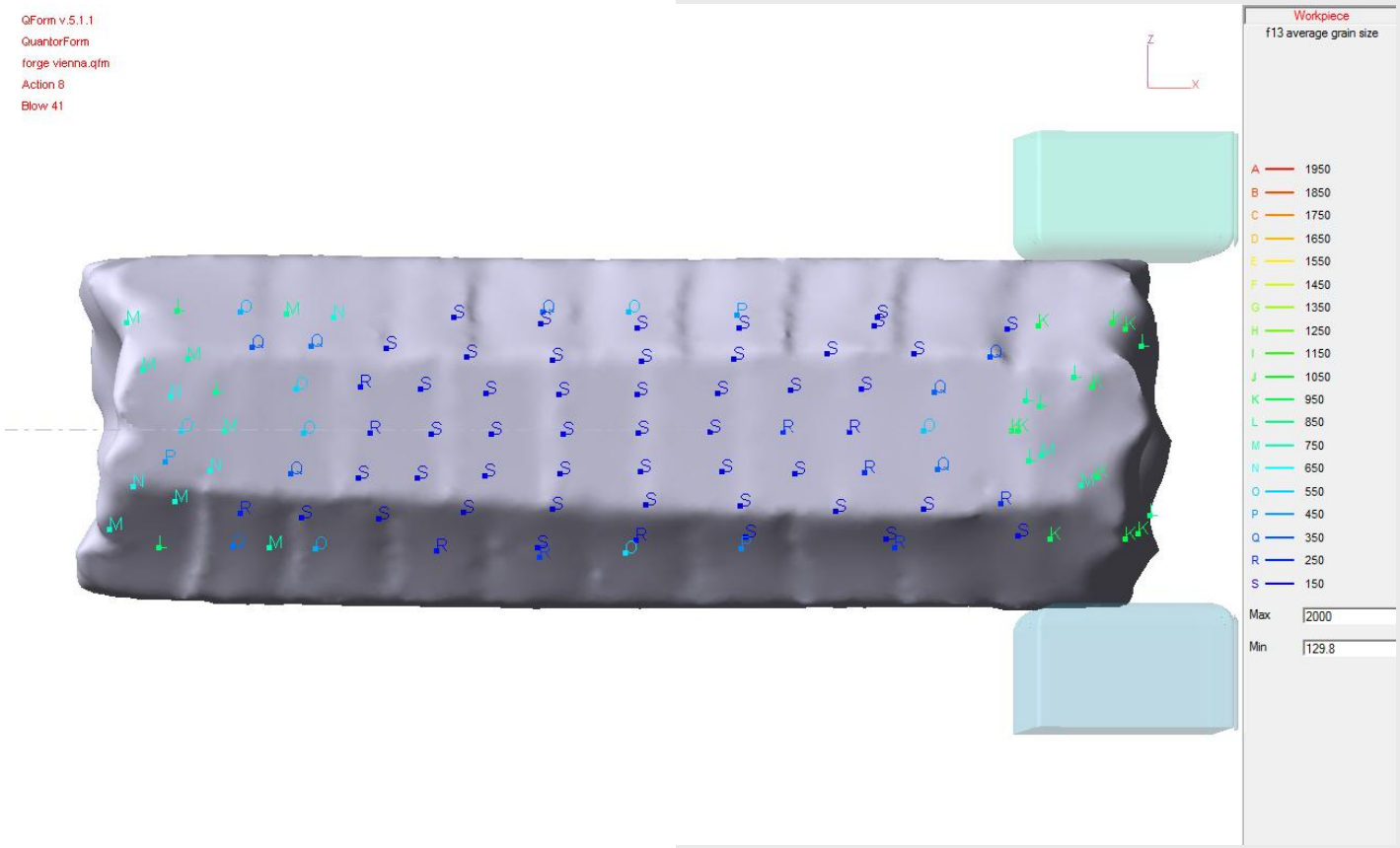
Grain size increasing during reheat due to recrystallisation

Temperature increasing during reheat



Open die forging simulation

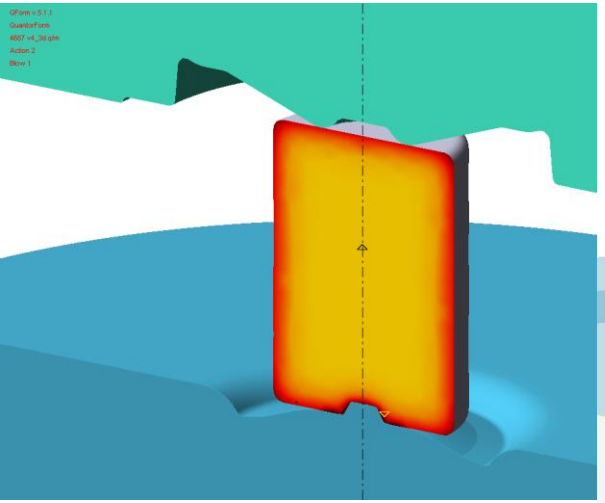
Final grain size after cogging and cooling

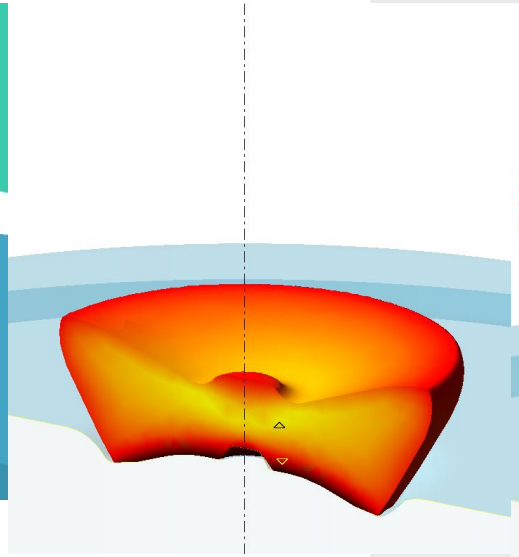


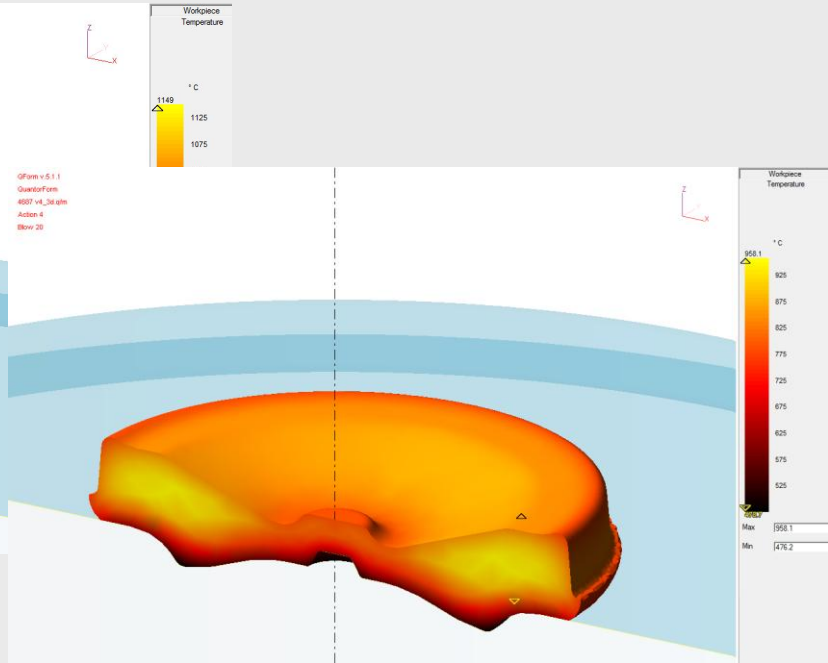
Disk forging: grain size prediction for INCONEL 718*

Initial average grain size is ASTM 6. The following steps were simulated

1. Heating to 970 C in a gas furnace during 200 min
2. The first series blows.
3. Heating to 970 C during 20 min
4. The second series blows.
5. Heat treatment at 982 C in solution for 60 min
6. Quenching in oil for 30 min





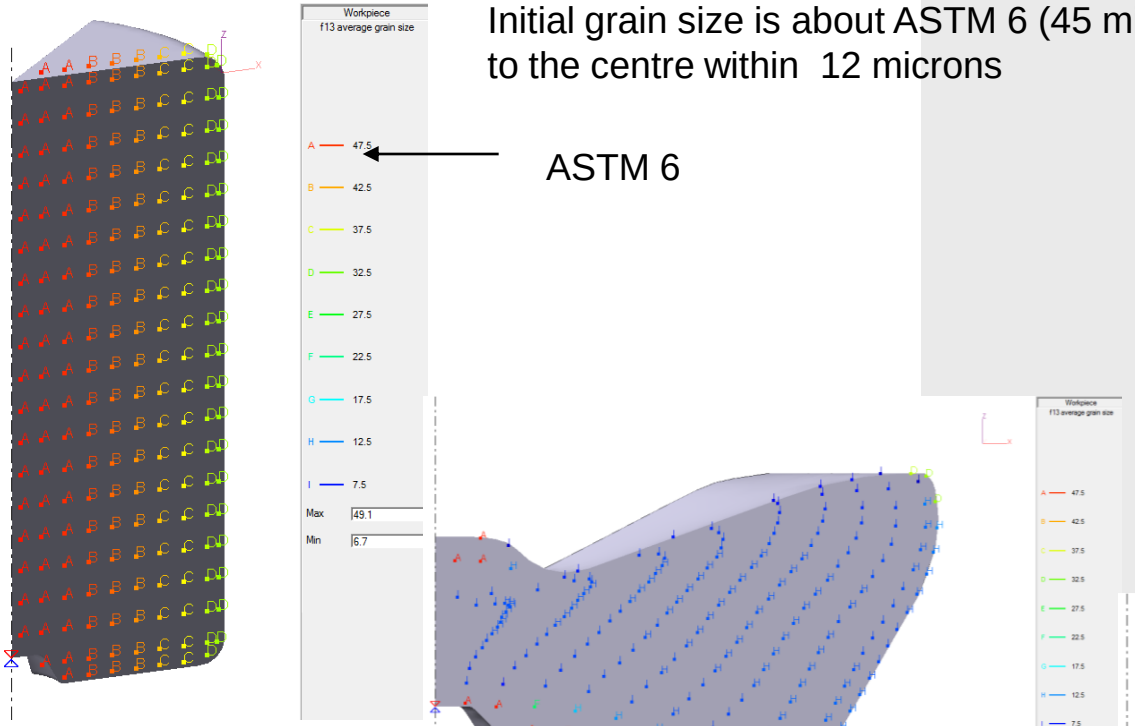


*) with permission of Wyman Gordon, Lincoln

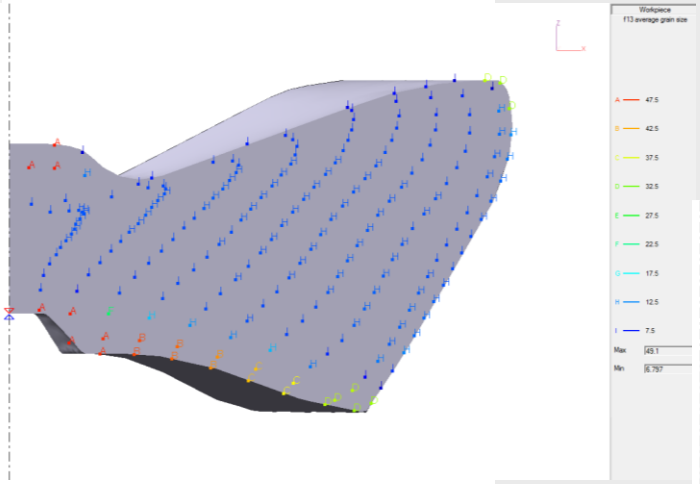
Grain size at different stages of the process

Initial grain size is about ASTM 6 (45 microns) with variation from the surface to the centre within 12 microns

ASTM 6

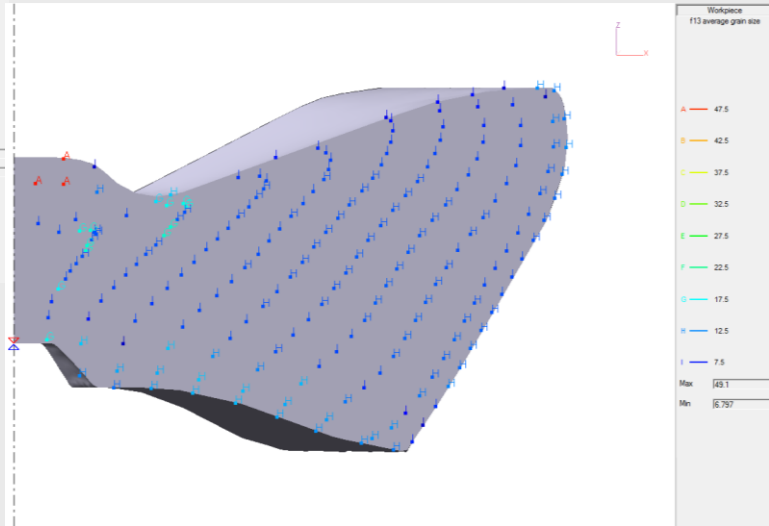


Grain size distribution in the billet

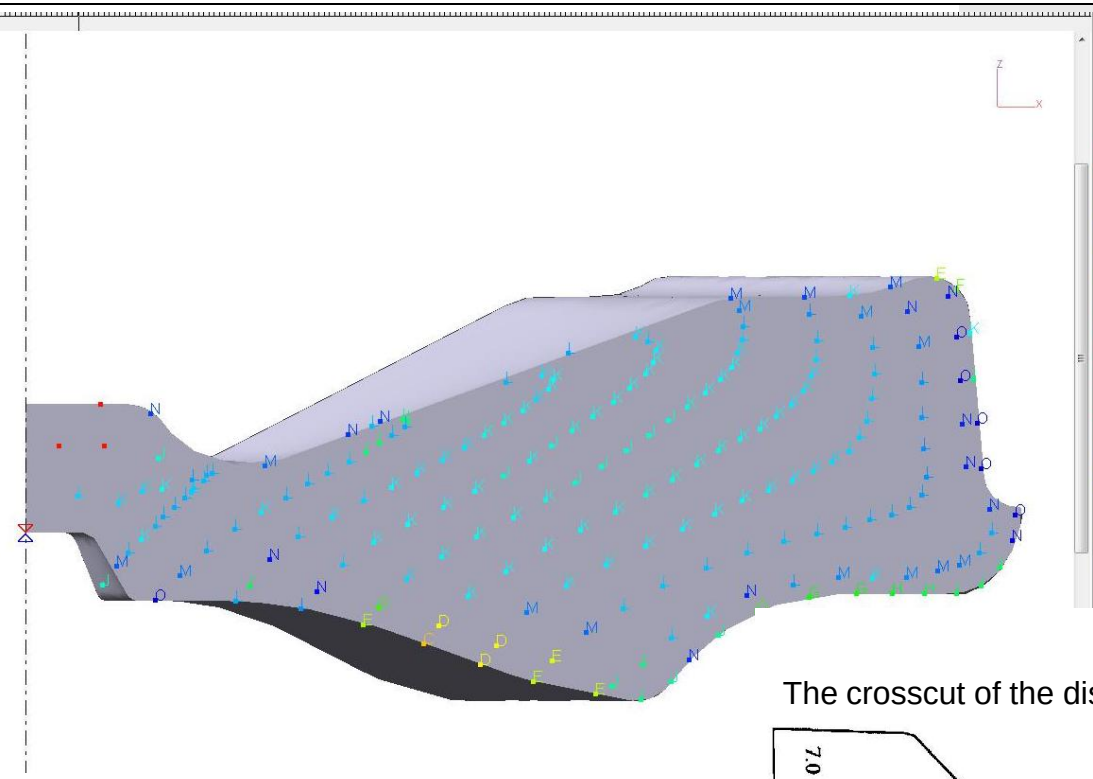


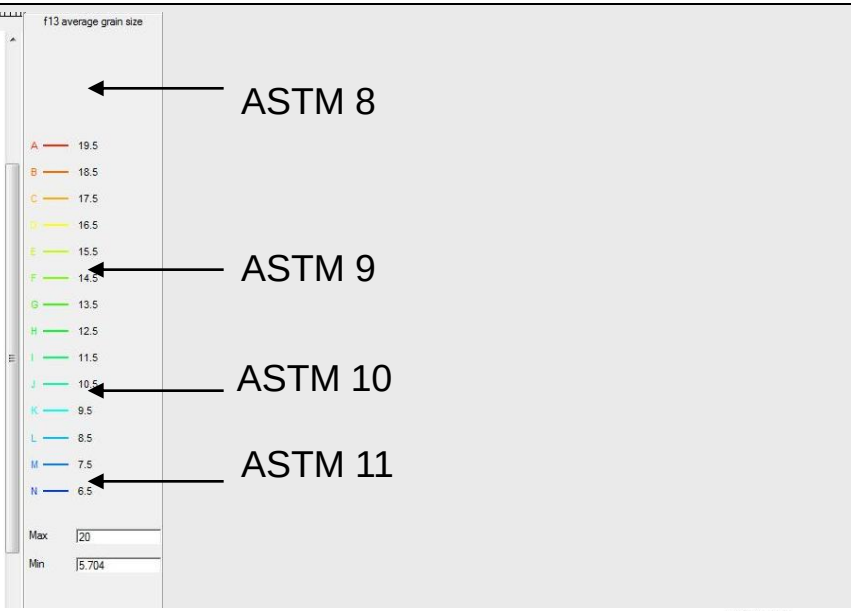
The grains after the first series of blows

The grains after the intermediate reheat



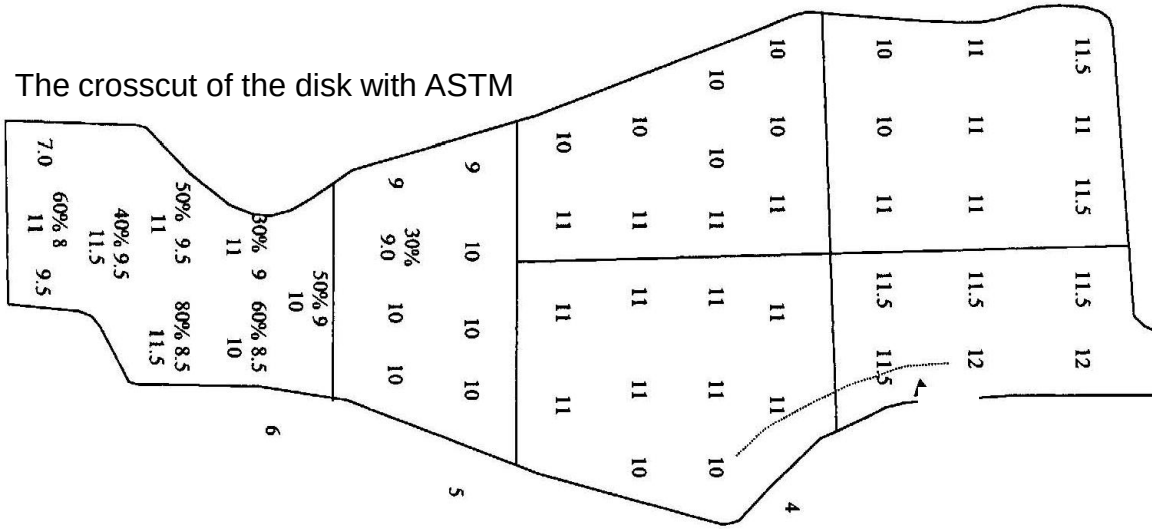
Good agreement of predicted and measured grain size





Final grain size after the second series of blows and heat treatment is from 7 to 10 microns that corresponds to ASTM 10 -11 as was shown experimentally

The crosscut of the disk with ASTM

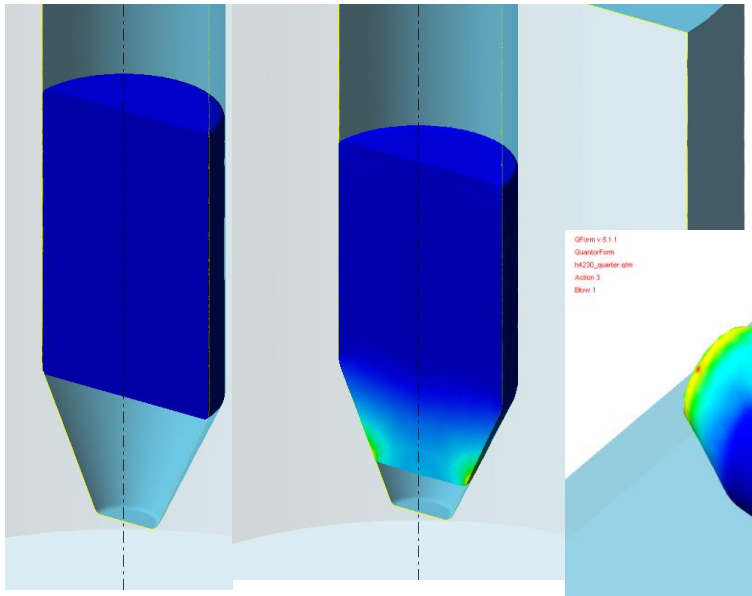


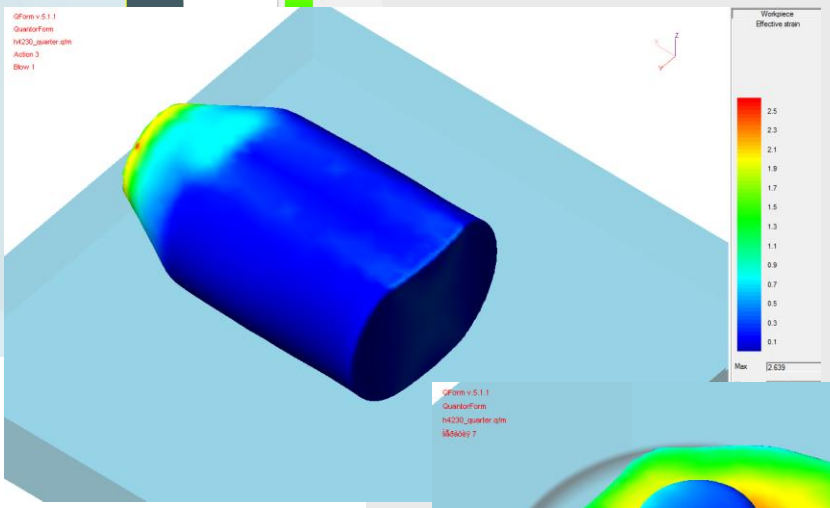
Case study No 2

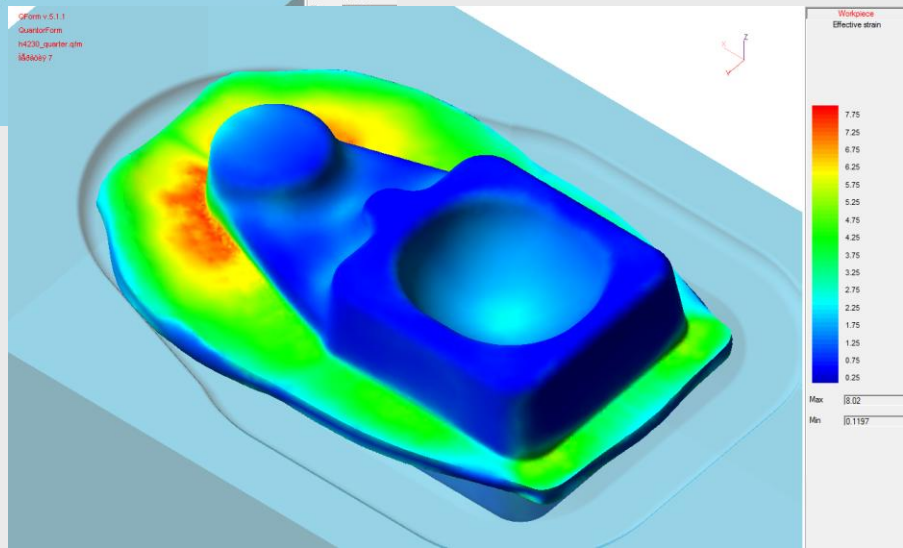
Aero Engine Gear Box Suspension Link

In collaboration with Mettis Aerospace (UK)

Metal forming and microstructure simulation: material Inconel 718



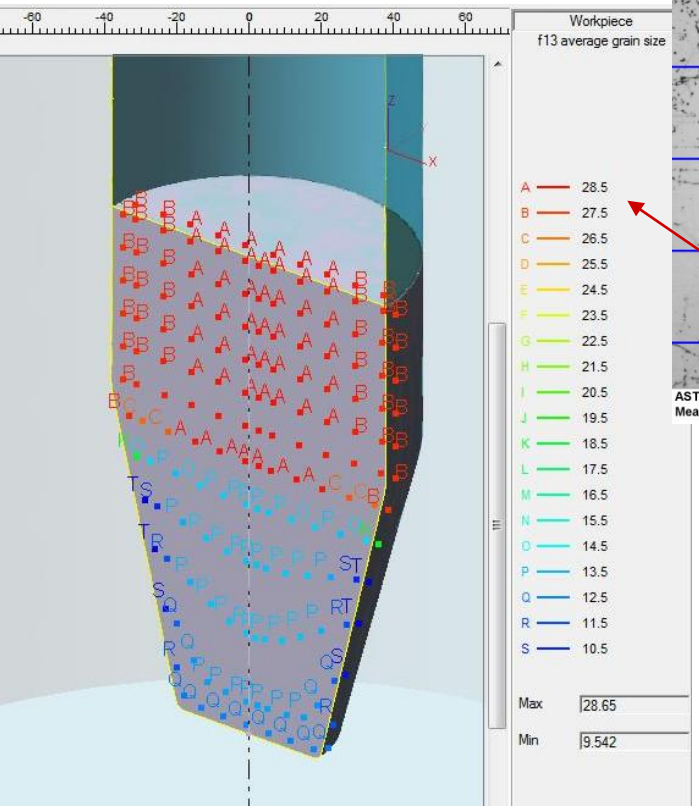




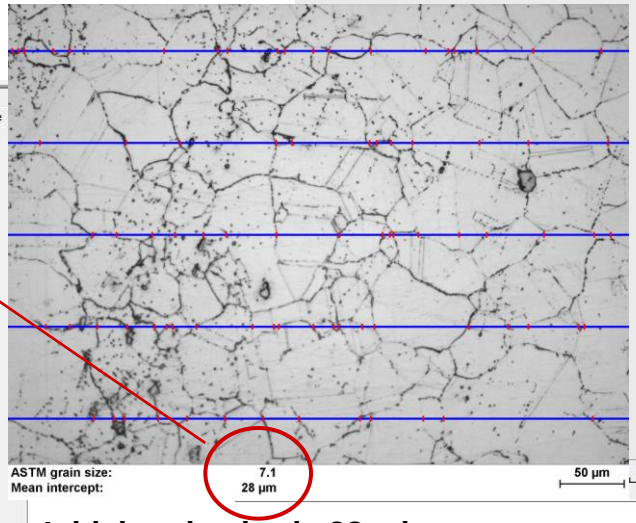
Three metal forming operations:

Initial grain size 28 microns
Initial temperature - 1080C

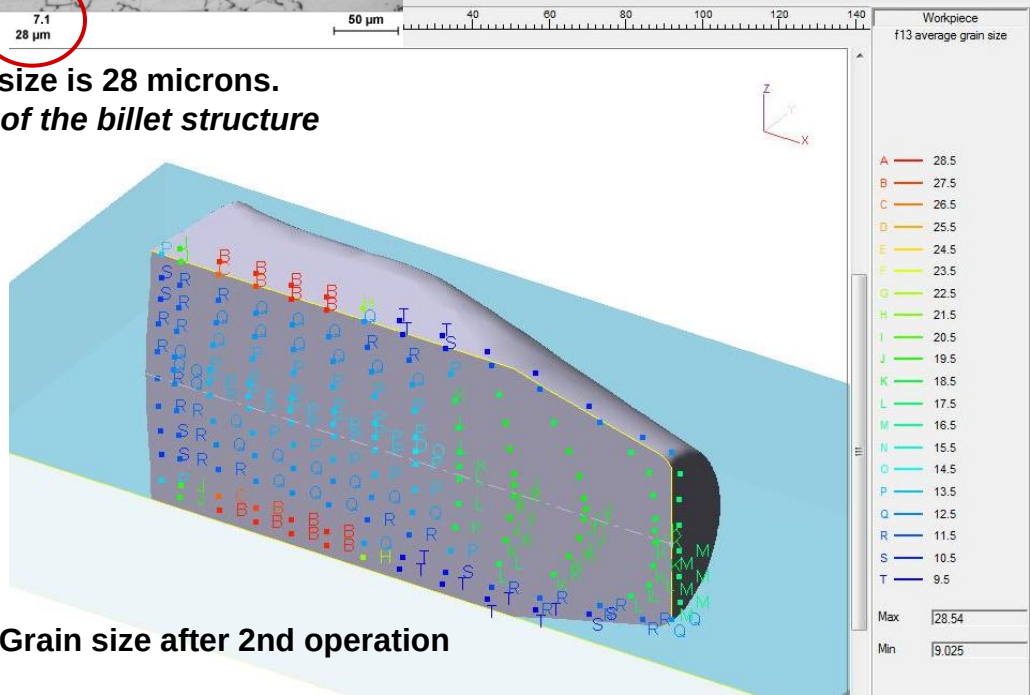
Grain size evolution in extrusion and flattening operations



Grain size after 1st operation

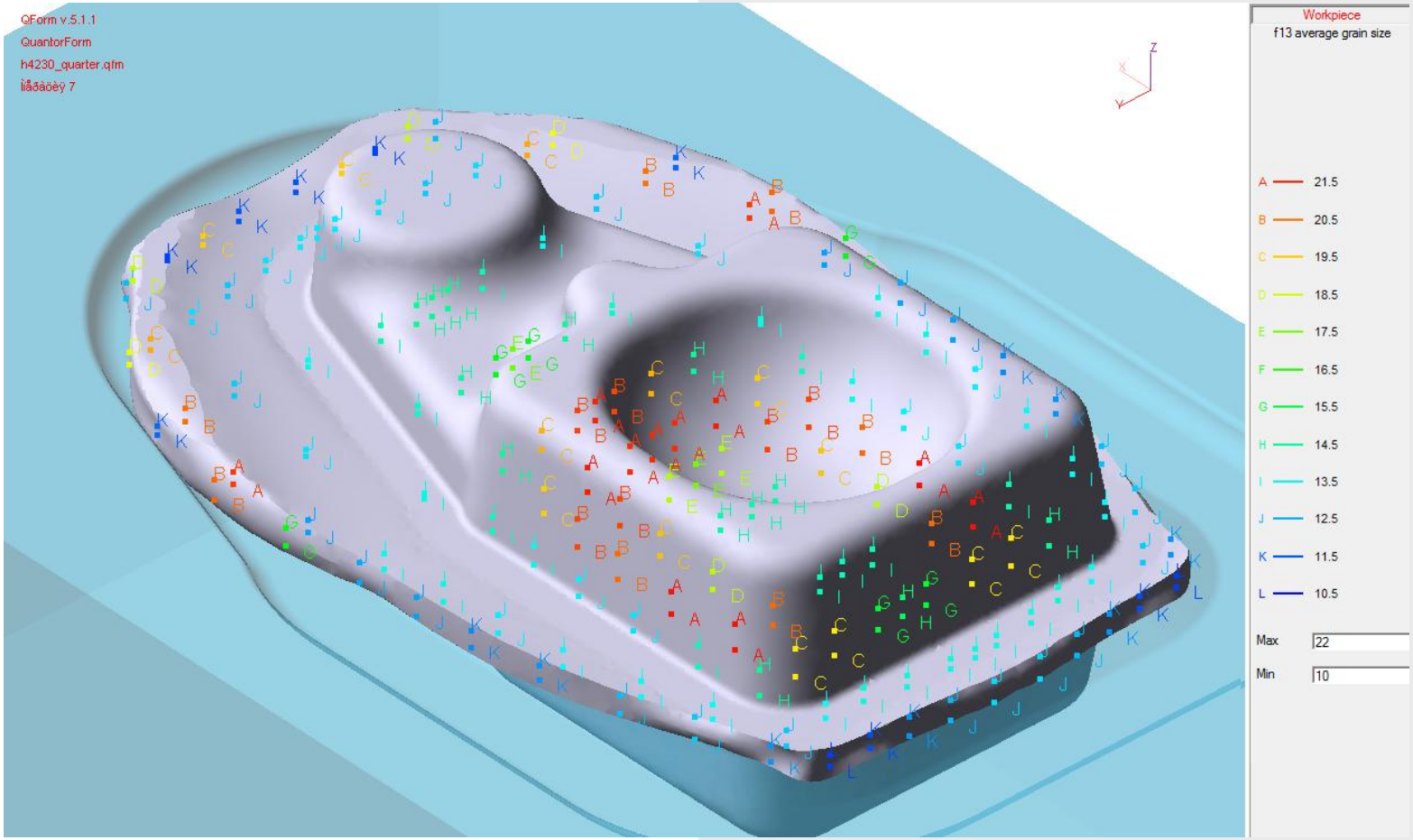


Initial grain size is 28 microns.
Microphoto of the billet structure

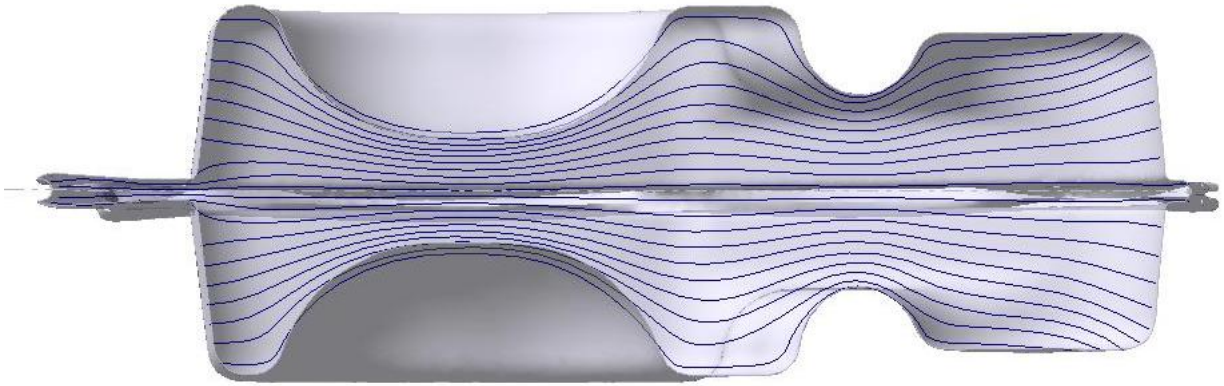


Grain size after 2nd operation

Finish product: general view

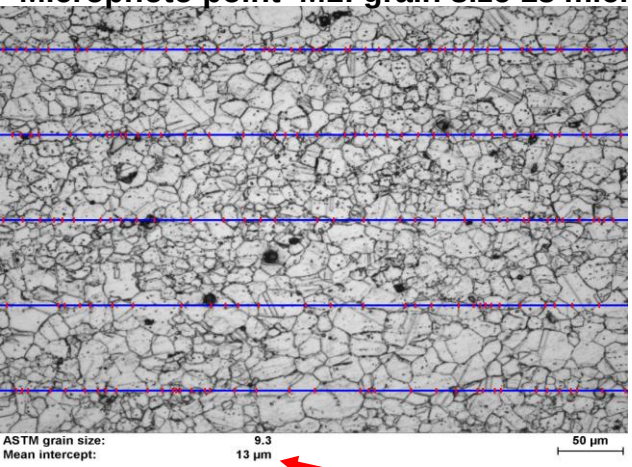


Grain flow in simulation and a in real forged part

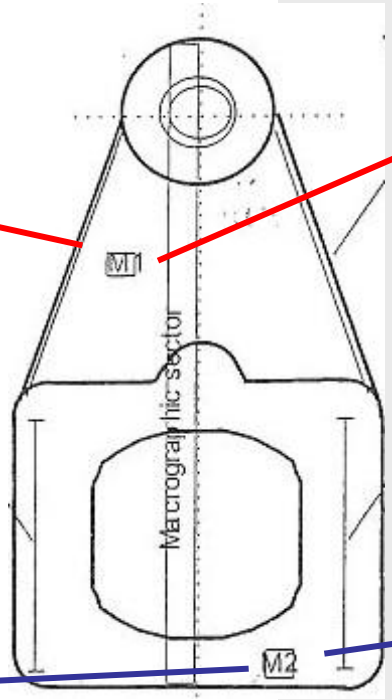


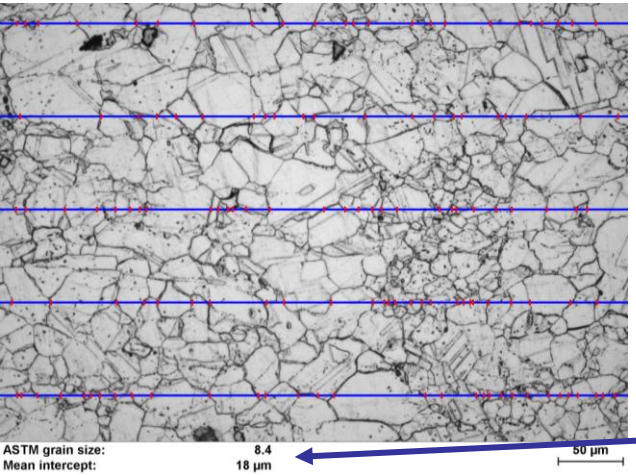
Grain size in control points M1 and M2: simulation and experiment

Microphoto point M1: grain size 13 microns

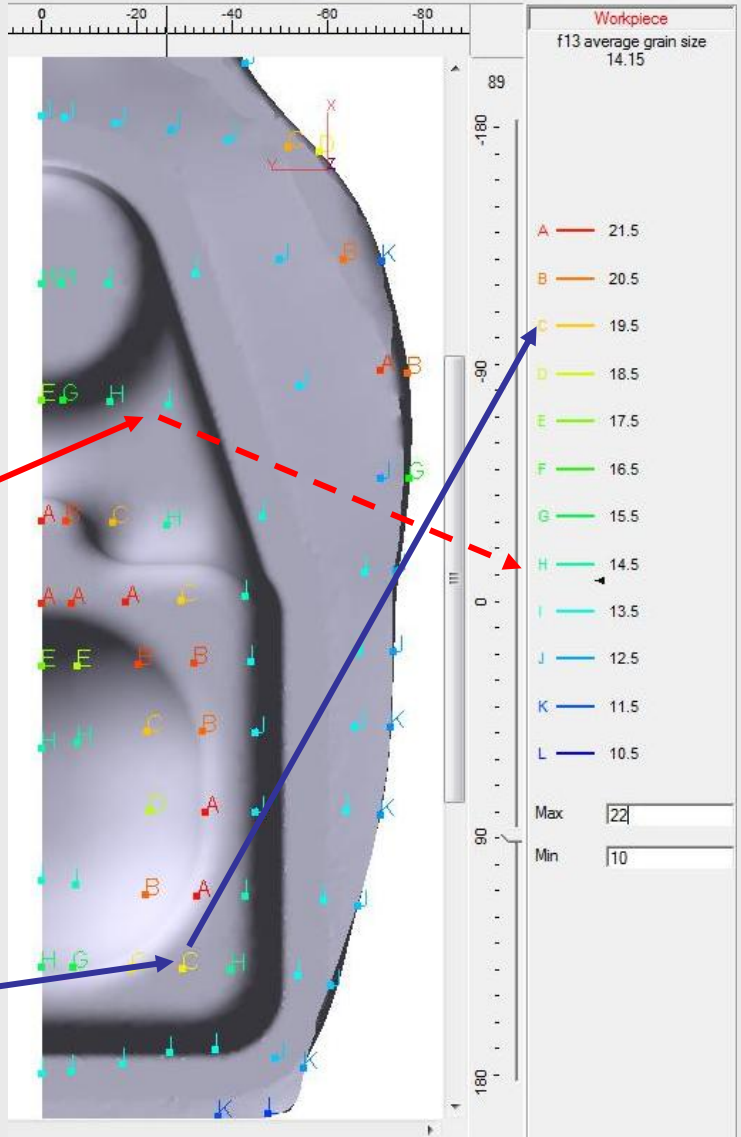


Forging Cut Up Plan





Microphoto point M3: grain size 18 microns



HT and MS modules provide additional value to simulation practice by predicting, control and optimisation of product properties