Härdbarhetens inverkan på formförändring

Delprojekt inom FFI-SMART (Vinnova)

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Project background

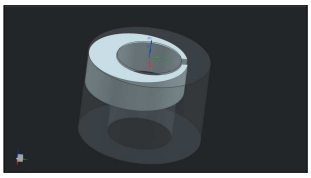
- To study the effect of hardenability on distortion, i.e. to account for the influence of alloying content from heat to heat in production.
- The long-term goal is to *"develop guidelines for minimizing the effect of variations in hardenability on distortion".*

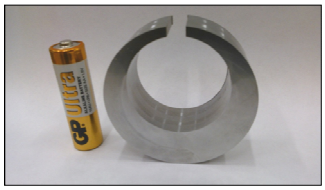
Method

- Part 1: Simple geometries
- Part 2: Production monitoring

Part 1: Simple geometries

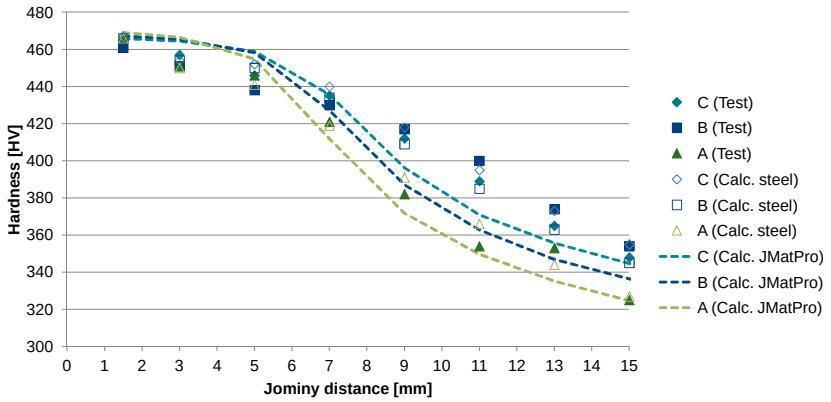
1. Steel grade: Tubes 16NiCrS4 (Ovako 146S)
2. 3 different heats
3. Machining: C-rings and rings (∅70 mm)
   - C-rings: 30 in total (10 for every heat)
   - Rings: 120 in total (40 for every heat)
4. Stress-relief annealing
5. Shape determination
6. Hardening was done without carburization:
   - C-rings: Vacuum HT and gas-/oil quenching
   - Rings: Atmosphere HT and salt-/oil quenchi
7. Distortion analysis



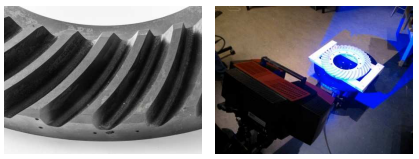


Part 1: Hardenability, 16NiCrS4

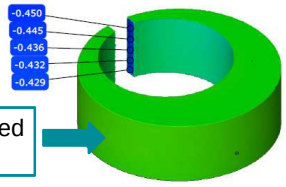
Experimental and calculated hardenability of three heats (A, B and C)



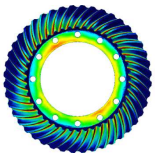
Part 1: Distorsion analysis

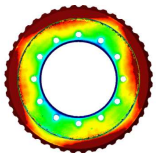


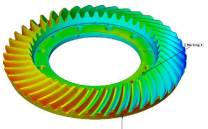
Gap distortion [mm]



3D-scanned C-ring



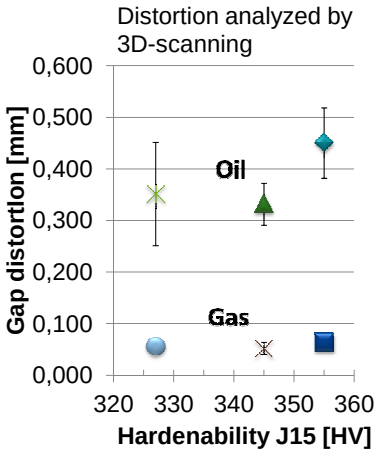




Example: 3D-scanned crown wheel

- 3D scanning or coordinate-measuring machine (CCM)
- 3D scanning is done before and after heat treatment. It enables full visualization and evaluation of distortions.

Part 1: Hardness and distortions C-rings



- Hardness on the flat surface.
- Three measurements per C-ring.
- Mean value over every HT.

	Hardness [HRC]	
Charge	Oil	Gas
C	39,9 ± 1,3	28,3 ± 0,9
B	39,7 ± 1,7	28,0 ± 1,6
A	41,3 ± 2,2	28,0 ± 2,7

Increased hardenability of heats

Part 1: Simple geometries

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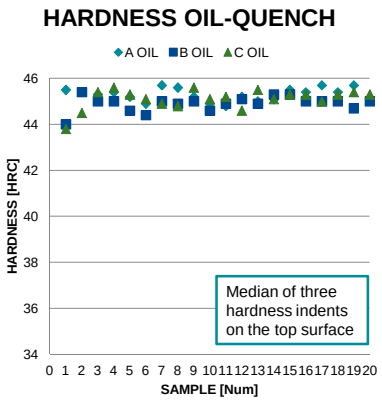
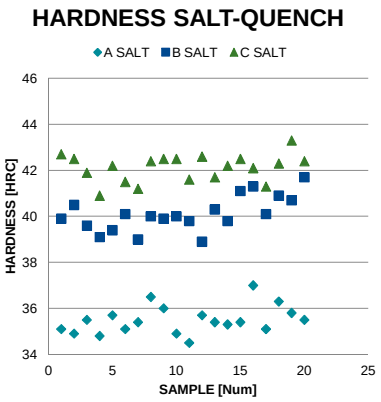
6. Distortion analysis

Part 1: Hardness rings





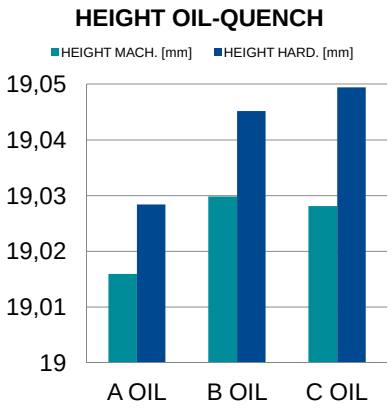
Part 1: Hardness C-rings and Rings

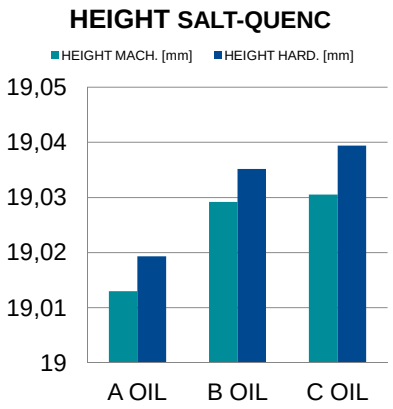
	C-ring Hardness [HRC]		Ring Hardness [HRC]	
Charge	Oil	Gas	Oil	Salt
C (V5174)	39,9 ± 1,3	28,3 ± 0,9	45,0 ± 0,6	42,1 ± 0,7
B (V6017)	39,7 ± 1,7	28,0 ± 1,6	44,9 ± 0,5	40,1 ± 1,2
A (V7628)	41,3 ± 2,2	28,0 ± 2,7	45,3 ± 0,4	38,5 ± 0,7

Increased hardenability of heats

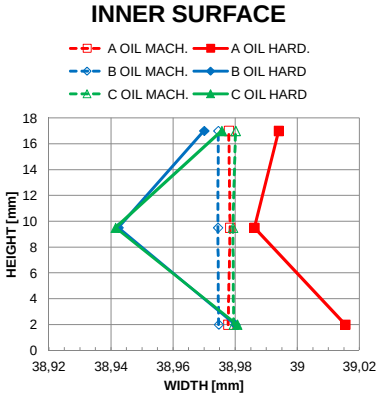
Hardness, mean value of all components with three indents/piece. Hence, 15 indents/HT for C-rings and 60 indents/HT for rings. Error given as ±1stdav.

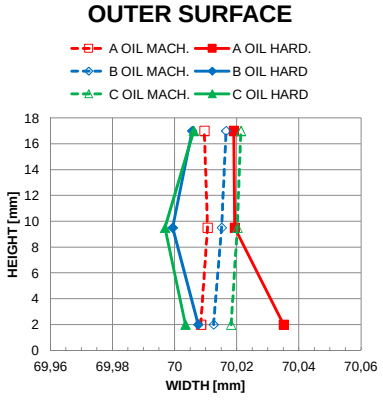
Part 1: Distortion of quenched rings



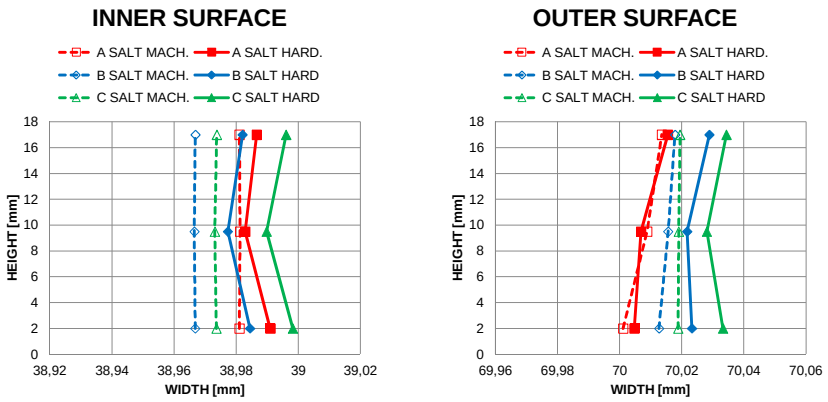


Part 1: Distortion of quenched rings
Oil quenching



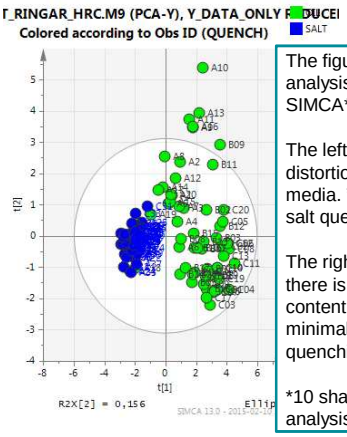


Part 1: Distortion of quenched rings
Salt quenching

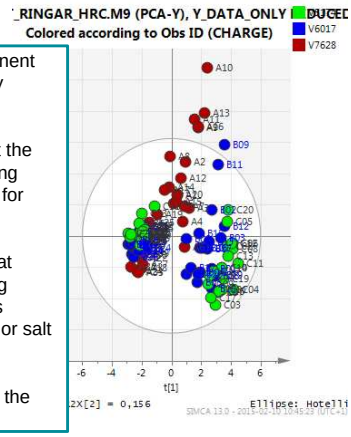


Part 1: Distortion of quenched rings

Oil and salt



Heat A, B and C



The figures show a principal component analysis (PCA) of the rings, done by SIMCA*.

The left-hand side figure shows that the distortion is affected by the quenching media. ”Distortion space” is smaller for salt quenching.

The right-hand side figure shows that there is a strong influence of alloying content on distortion. Overlapping is minimal among rings from either oil or salt quenching.

*10 shape aspects were included in the analysis

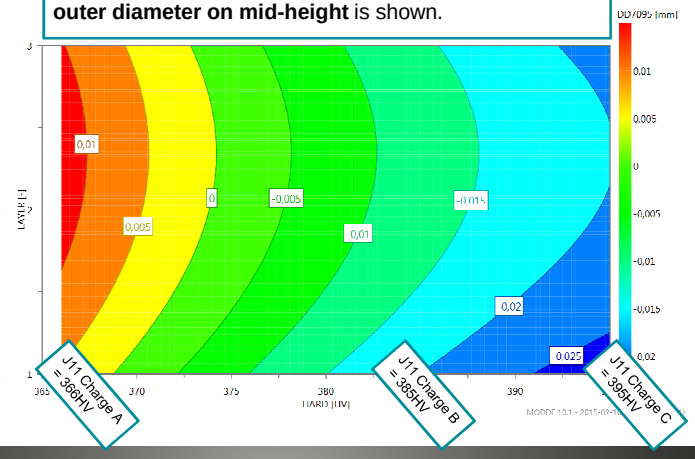
Part 1: Distortion of quenched rings

Data can be treated according to DoE, to study the effect of furnace layer and hardenabiliy. Here the effect on **outer diameter on mid-height** is shown.

Layer 3

Layer 2

Layer 1



Part 2: Production monitoring

- Study the effect of hardenability on distortion of crown wheels
- Reduce influence of casting and forging → One supplier
- In total, forgings were collected from five different heats
- Every heat was represented of about 20 crown wheels
- All forgings were machined in sequence
- Shape determination before and after heat treatment
- Heat treatment in sequence on center furnace row.

Part 2: What we have analyzed

- Alloying content – Is there a difference among the heats?
- Average distortion – To compare with target values
- Identify outliers – Crown wheels with relatively large distortion
- Distortion vs. heat – Can we identify trends?
- Multivariate data analysis – Is it a useful tool?

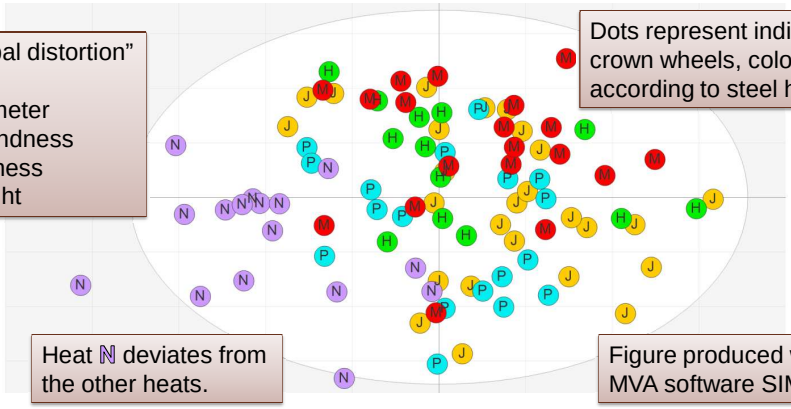
Part 2: Alloying content

- Hardenability: Heats can be divided into two groups (Group 2 higher)
  - Group 1 – Heats M, N och P
  - Group 2 – Heats H och J (+C, Cr, Ni / –Cu)
- Micro-alloying content
  - Heat N and P has a much higher content of Al.
  - Heat P also has an increased content of Ti, relative to the other heats

Part 2: ”Global distortion”

The figure is an graphical interpretation of six “global distortion” measurements. That is, two crown wheels which are superpositioned in the figure have identical distortions. If there would be no influence of steel heat (e.g. hardenability) all points (representing individual crown wheels should be scattered around origin with no clear separation among the heats.

”Global distortion” e.g.
•Diameter
•Roundness
•Flatness
•Height



Dots represent individual crown wheels, colored according to steel heat

Heat N deviates from the other heats.

Figure produced with MVA software SIMCA

Slutsatser - sammanfattning

Allmänt formförändringar

- Vid härdning → Bildas martensit → Formförändring → Kompenserbar
- Oönskade formförändringar som visar sig efter värmebehandling är komplext och orsakas av många faktorer
- Stål och tillverkningskedjan bygger in bärare av formförändringspotenial som visar sig först efter värmebehandling.

Från detta projekt – fokus härdbarhetens inverkan på formförändringar

- Härdbarhet är en viktig faktor att beakta för att minimera formförändring:
  - Var konsistent vid beräkning eller provning av härdbarhet. Dokumentera och följ upp.
  - Legeringselement som ej fångas av härdbarhet (t ex Al, Ti, Al/N) inverkar.
- Förändringar hos ståleverantör eller smedja måste tas hänsyn till.
- Finns goda förutsättningar att systematiskt studera formförändringar genom produktionsuppföljning. Identifiera faktorer och håll så många som möjligt konstanta, variera härdbarhet. Multivariat dataanalys är ett bra verktyg.
- Spårbarhet till ugn, bana, lager och position

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Thank you for your attention!