Induction hardening:
Effect of Bainite in the Case Layer on Fatigue Strength

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Objective

- To investigate how bainite content in the case layer affects fatigue strength of induction hardened components.

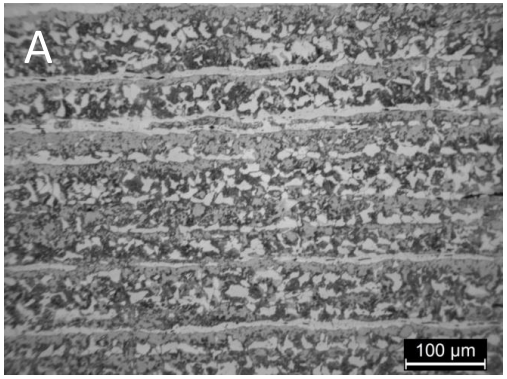
- To provoke bainite formation in the case layer by altering the induction hardening process.

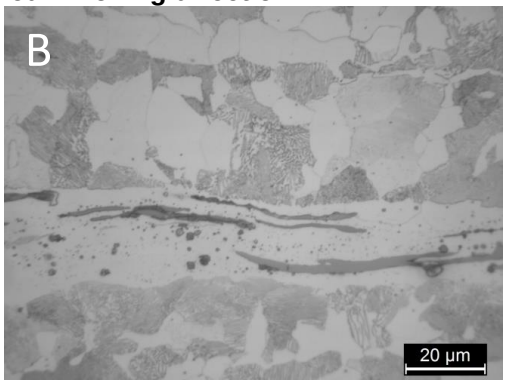
Material: Steel grade C45 (AISI 1045)

Alloying content of C45 (AISI 1045)

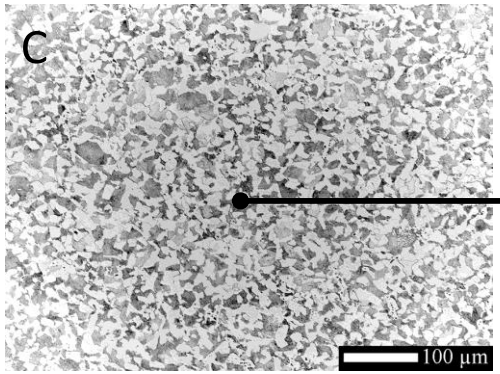
C	Si	Mn	P	S	Cr	Ni	Mo	Cu
0.44	0.20	0.68	0.014	0.030	0.15	0.15	0.03	0.23

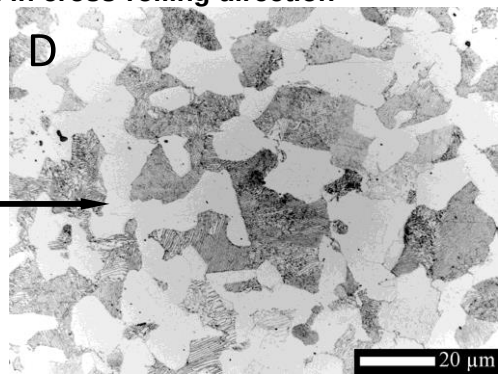
Microstructure as delivered in rolling direction





Microstructure as delivered in cross-rolling direction





Methods: Provoke bainite formation

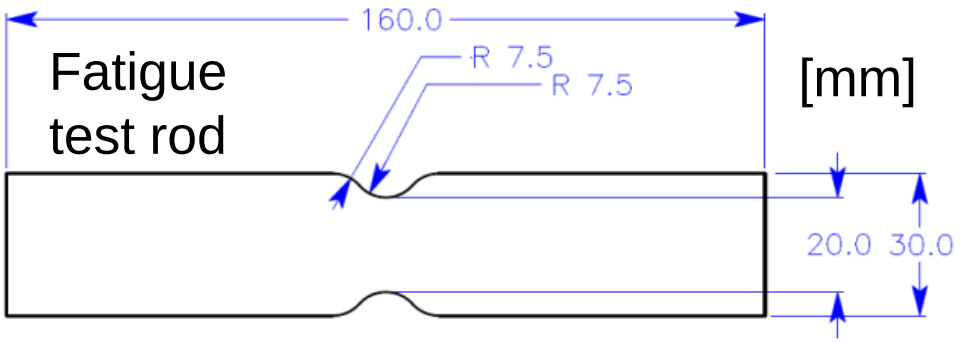
To provoke bainite formation a number of concepts were discussed:

I. Pre-heating to reach a higher core temperature.
II. Quench delay after heat treatment to change temperature gradient.
III. Reduce quenching power by flow or polymer concentration.
IV. Final surface temperature by changing heating power.
V. Affect hardenability by changing steel heat or grade.
VI. Partly dissolved as-delivered microstructure after heating.
VII. Turning after heat treatment to achieve a bainitic surface zone.

Methods: Induction hardening

Induction heating:

- Frequency: 22 kHz
- Rotation: 300 rpm
- Power: 70 kW
- Heating time: 4.3 s
- Peak temperature: 985C



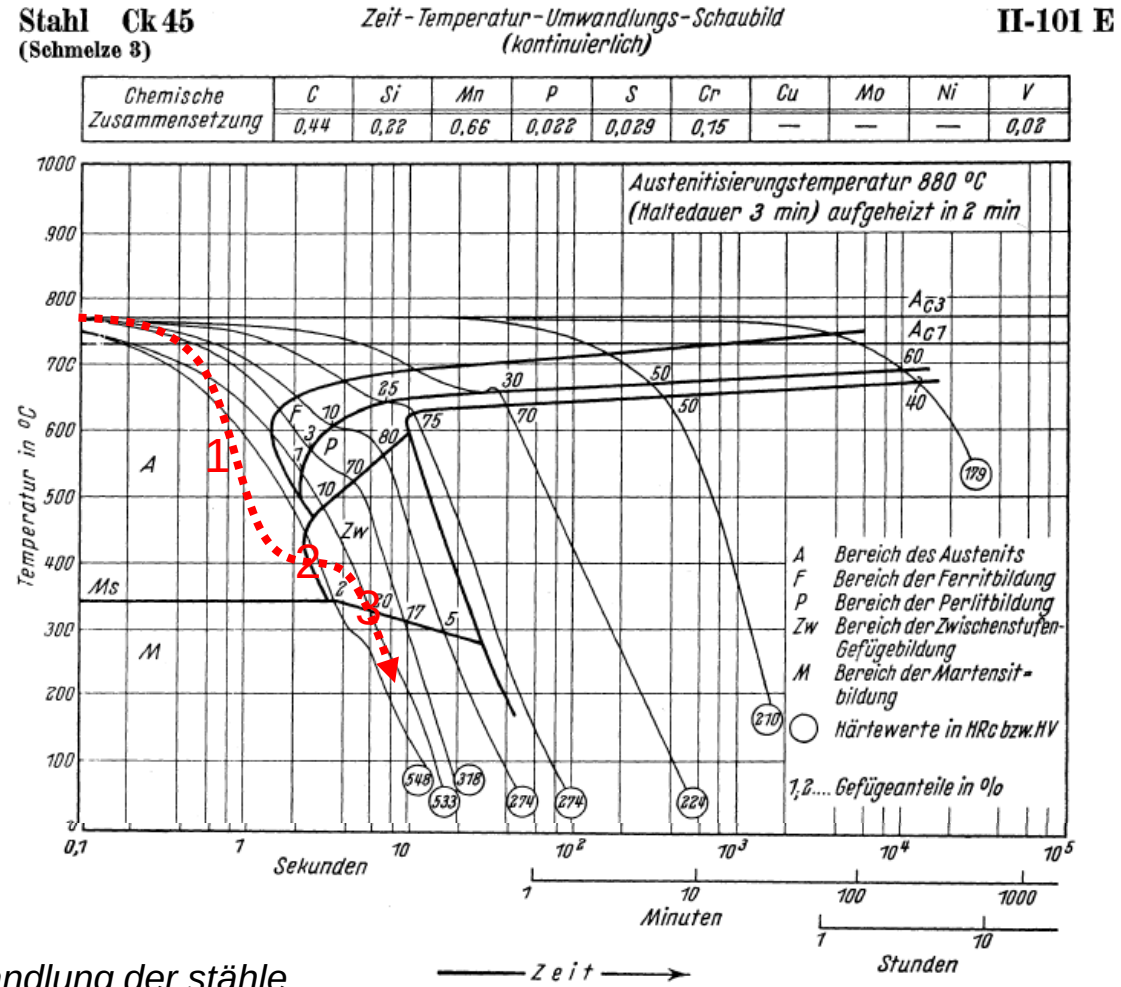
Induction hardening of test rods

Methods: Quenching

C45 has low hardenability.

Quenching:

1. Fast to avoid formation of ferrite and pearlite.
2. Short interrupt at the bainite regime.
3. Fast to form martensite



Reference: CCT from Atlas zur wärmebehandlung der stähle

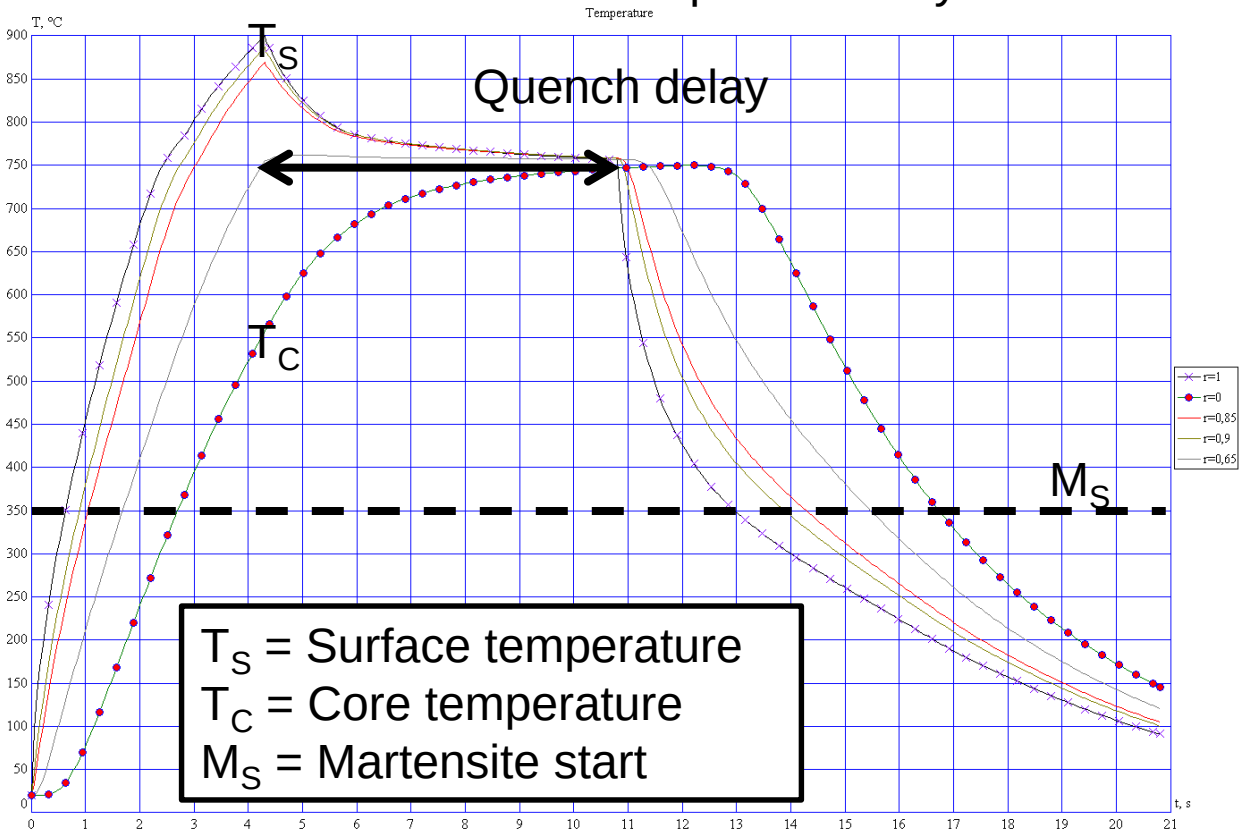
Methods: Quenching

- A screening study was done to evaluate induction hardening with quench delay and interrupted quenching. Based on the findings three series of fatigue test bars were produced:

Series	Description (as programmed in PLC)
A – Reference	Direct quenching for 30 seconds.
B – Quench delay	2.5 s holding time before 30 seconds quenching.
C – Interrupted quench	Quenching for 0.6 seconds, then 0.8 seconds quench interruption followed by 30 seconds final quenching.

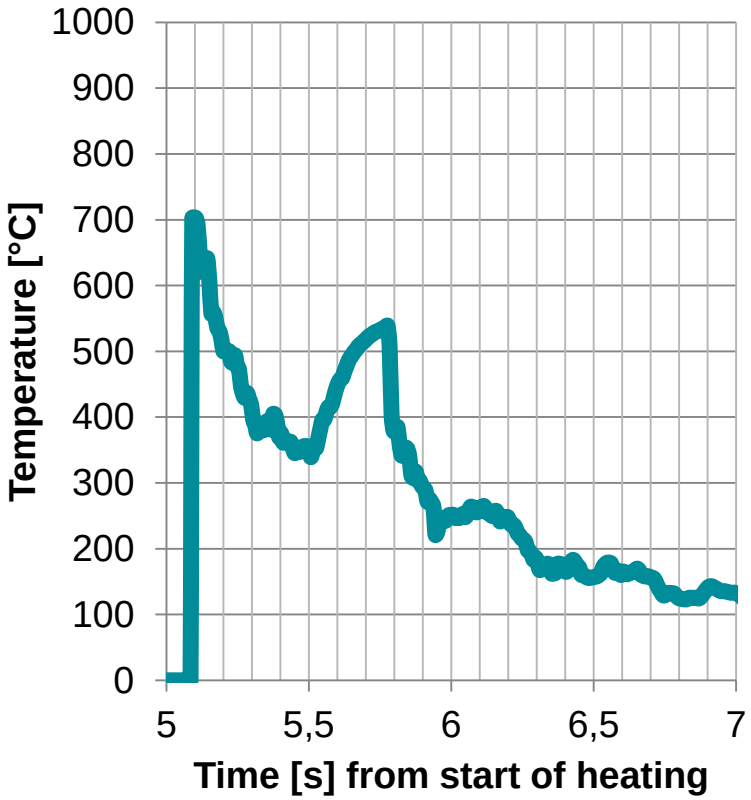
Methods: Quenching

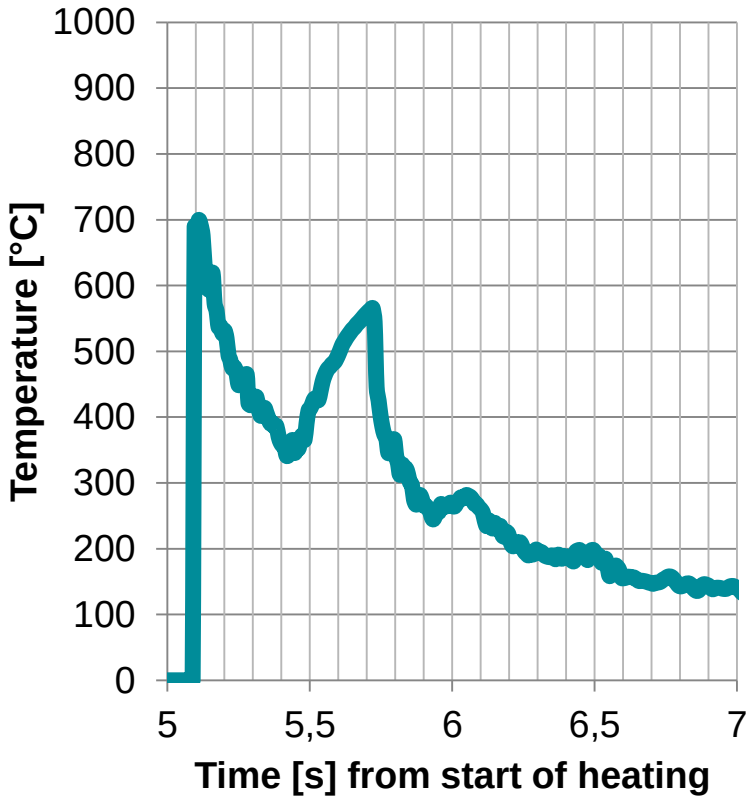
ELTA simulation of quench delay.



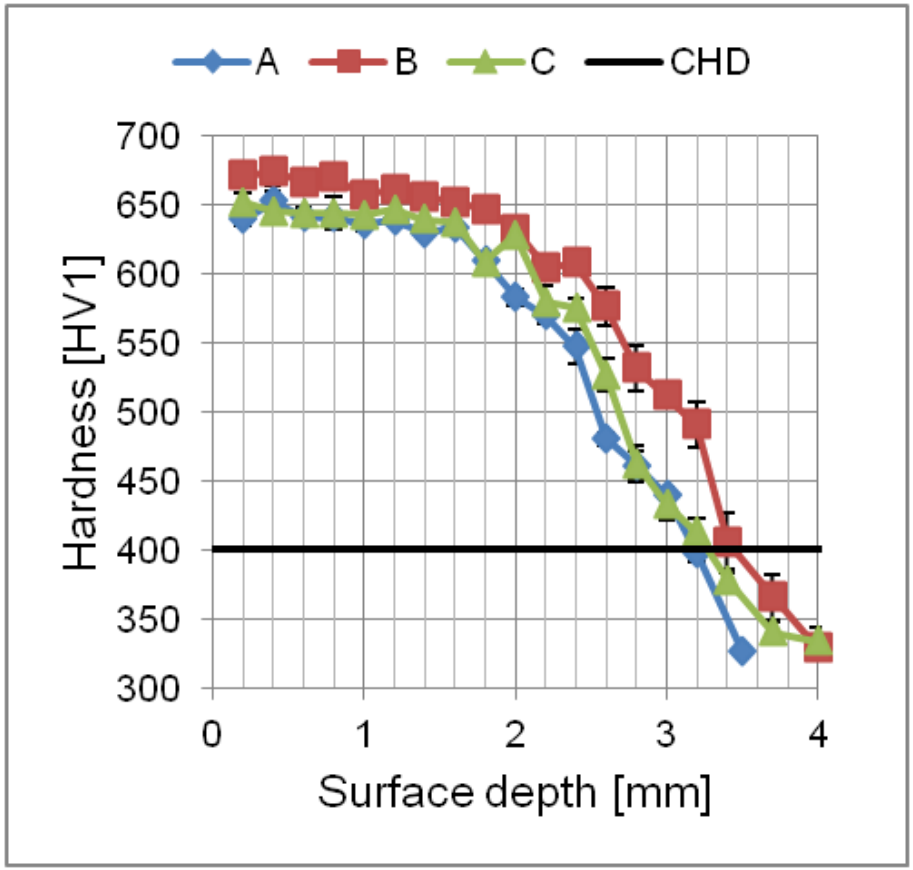
Methods: Quenching

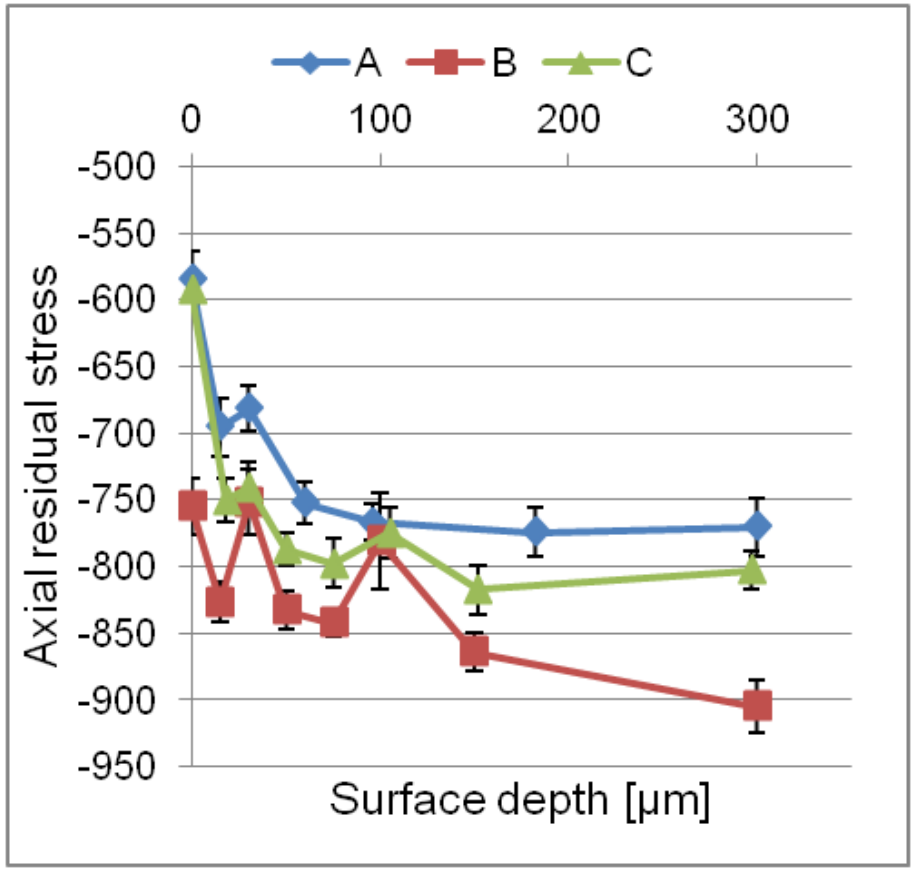
Interrupted quench, Series C, temperature measurements showed good repeatability. Temperature profiles show data from two heat treatments.





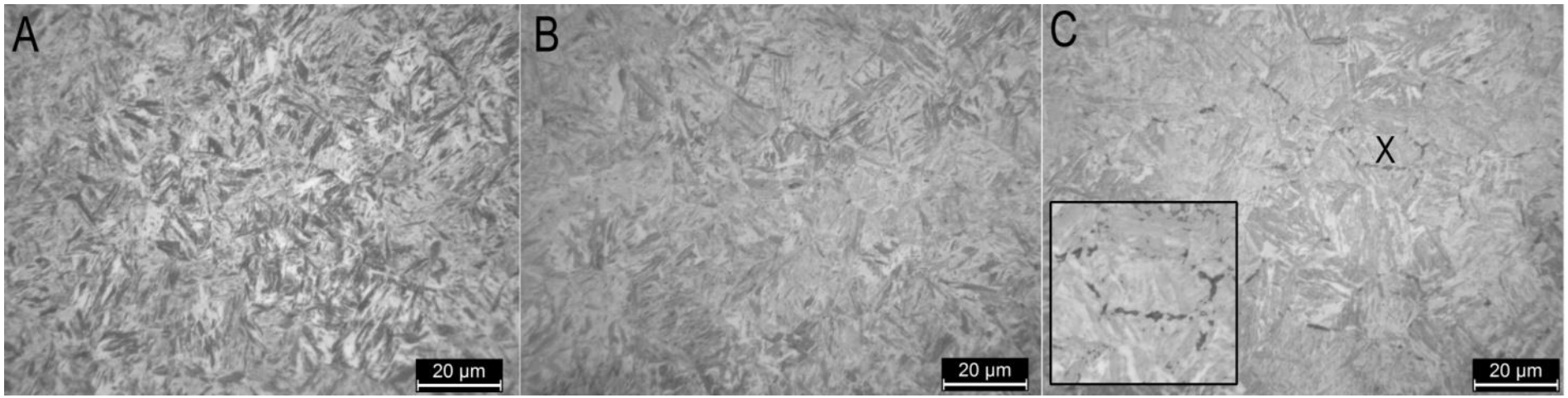
Results: Hardness and Residual stresses





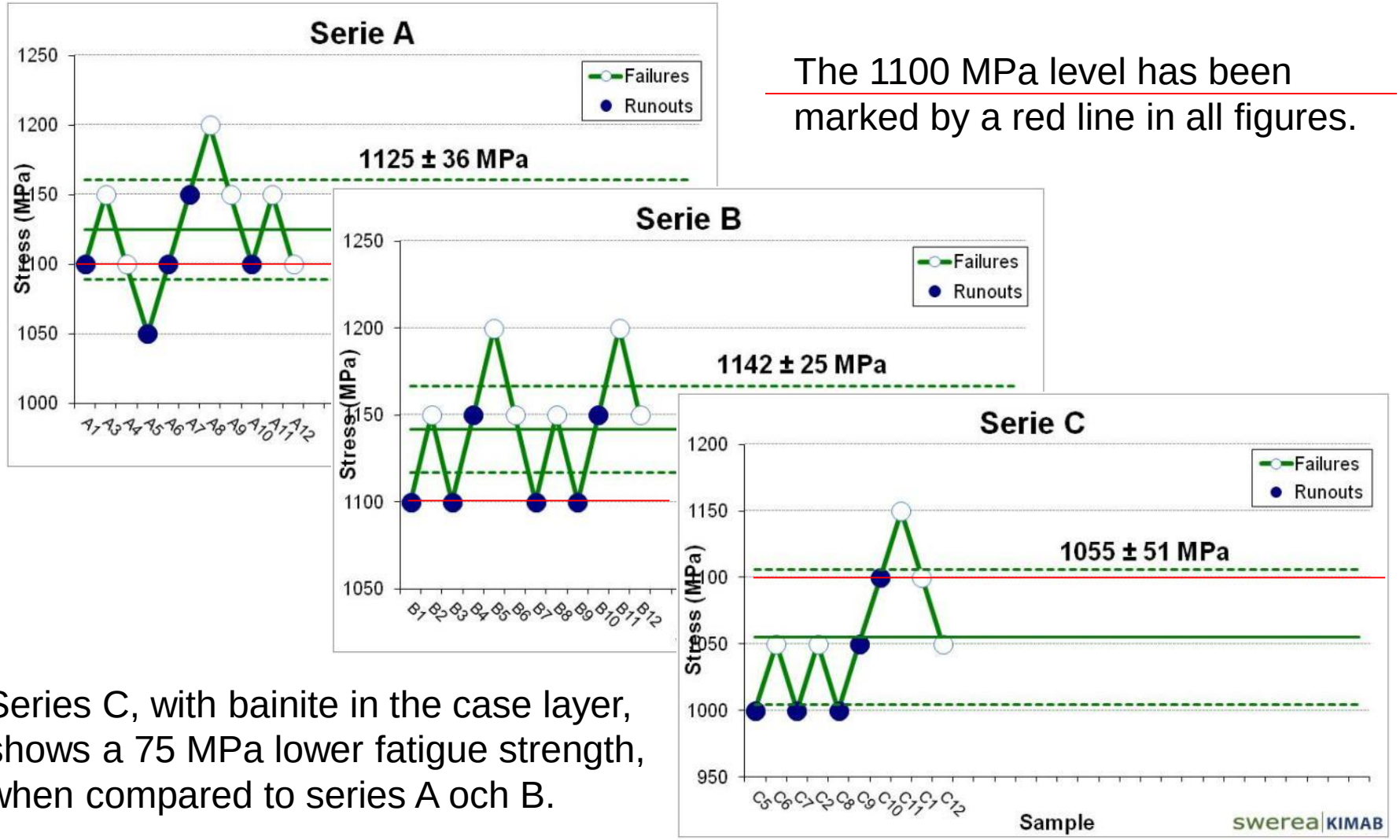
Results: Microstructure characterization

To define the presence of bainite we adopted:
"B_T": Depth with first tendency for bainite formation in 1000x magn.
"B_U": Depth with apparent bainite formation in 200x magn.



A – Reference		B – Quench delay		C – Interrupted quench	
B_T:	1.0 mm depth	B_T:	0.8 mm depth	B_T:	0.1 mm depth
B_U:	1.4 mm depth	B_U:	1.4 mm depth	B_U:	0.4 mm depth

Results: Fatigue testing

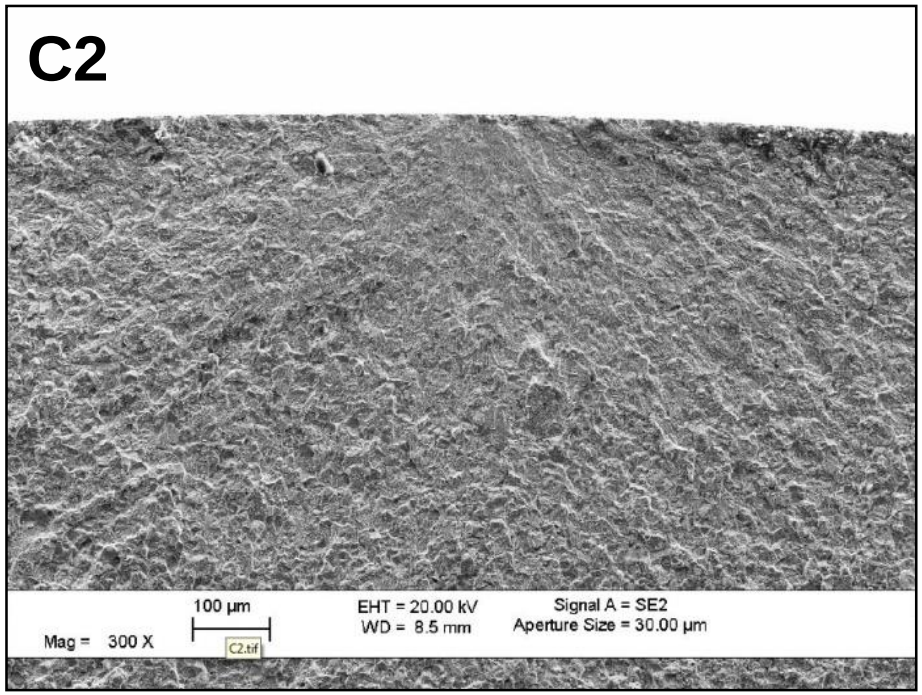


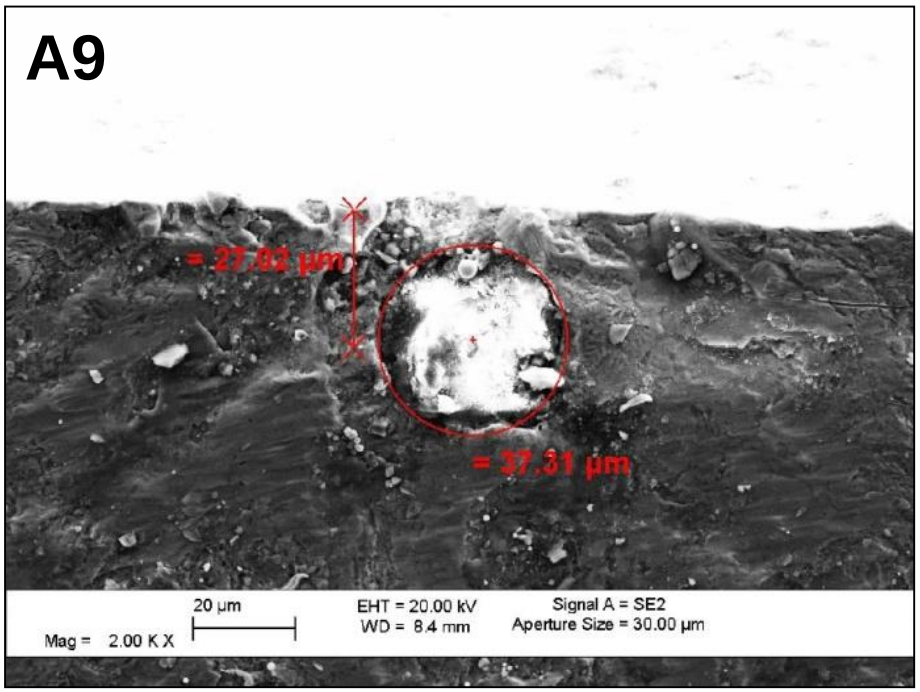
The 1100 MPa level has been marked by a red line in all figures.

Series C, with bainite in the case layer, shows a 75 MPa lower fatigue strength, when compared to series A och B.

Results: Fractography

Fractography micrographs showed surface initiation: (left) fracture surface of test rod C2, which is representative for all failed fatigue test rods except A9. (right) fracture surface of test rod A9 where a relative large inclusion was observed.





Results: Summary

Results from characterization of fatigue test rods.

	SHD	CHD	RSt	RSa	B_T	B_U	FS
Series A	640HV	3.2 mm	710	695	1.0 mm	1.4 mm	1125 ± 36 MPa
Series B	670HV	3.4 mm	920	825	0.8 mm	1.4 mm	1142 ± 25 MPa
Series C	650HV	3.2 mm	760	750	0.1 mm	0.4 mm	1055 ± 51 MPa

Details of fatigue testing – runouts and failures.

	Series A		Series B		Series C	
Stress level [MPa]	Runout	Failure	Runout	Failure	Runout	Failure
1000	-	-	-	-	3	-
1050	1	-	-	-	1	3
1100	3	2	4	-	1	1
1150	1	3	2	4	-	1
1200	-	1	-	2	-	-
Total	5	6	6	6	5	5

Conclusion

- In summary, the results from the present work suggest that bainite will have a negative impact on fatigue strength of induction hardened steel-components. However, small amounts of bainite will neither affect hardness nor residual stresses; hence impact on fatigue strength by bainite is most likely facilitation of crack initiation and -growth.

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