Cooling rate effects on mechanical properties at microscale of a heat resistant steel 30CrMoNiV5-11

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Motivation

Understanding how cooling rate and tempering affect the microstructure and local mechanical response of heat-resistant steels is key to improving their performance in demanding applications.

Methods

- Austenitizing and quenching.
- Tempering.
- EBSD analysis.
- Nanohardness mapping.

	Heat treatment	Heating rate (ºC/s)	Peak temperature (ºC)	Soaking time (min)	Cooling rate (ºC/s)
	Austenitization	5	950	30	0,05
					0,5
					5
					50

Heat treatment	Soaking temperature (ºC)	Soaking time (min)
Tempering	680	45

Material (wt. %)

%C	%Si	%Mn	%Cr	%Mo	%Ni	%V	%Cu	%S	%P
0,28	0,10	0,65	1,37	1,08	0,63	0,29	0,10	0,01	0,009

The studied material was obtained from an experimental meter-scale shaft, which underwent the manufacturing process illustrated bellow.

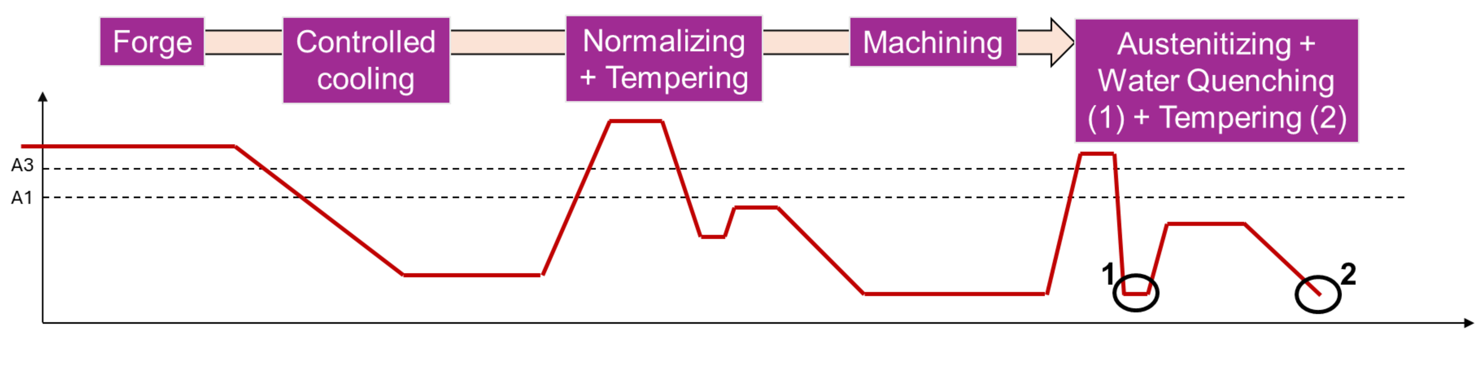
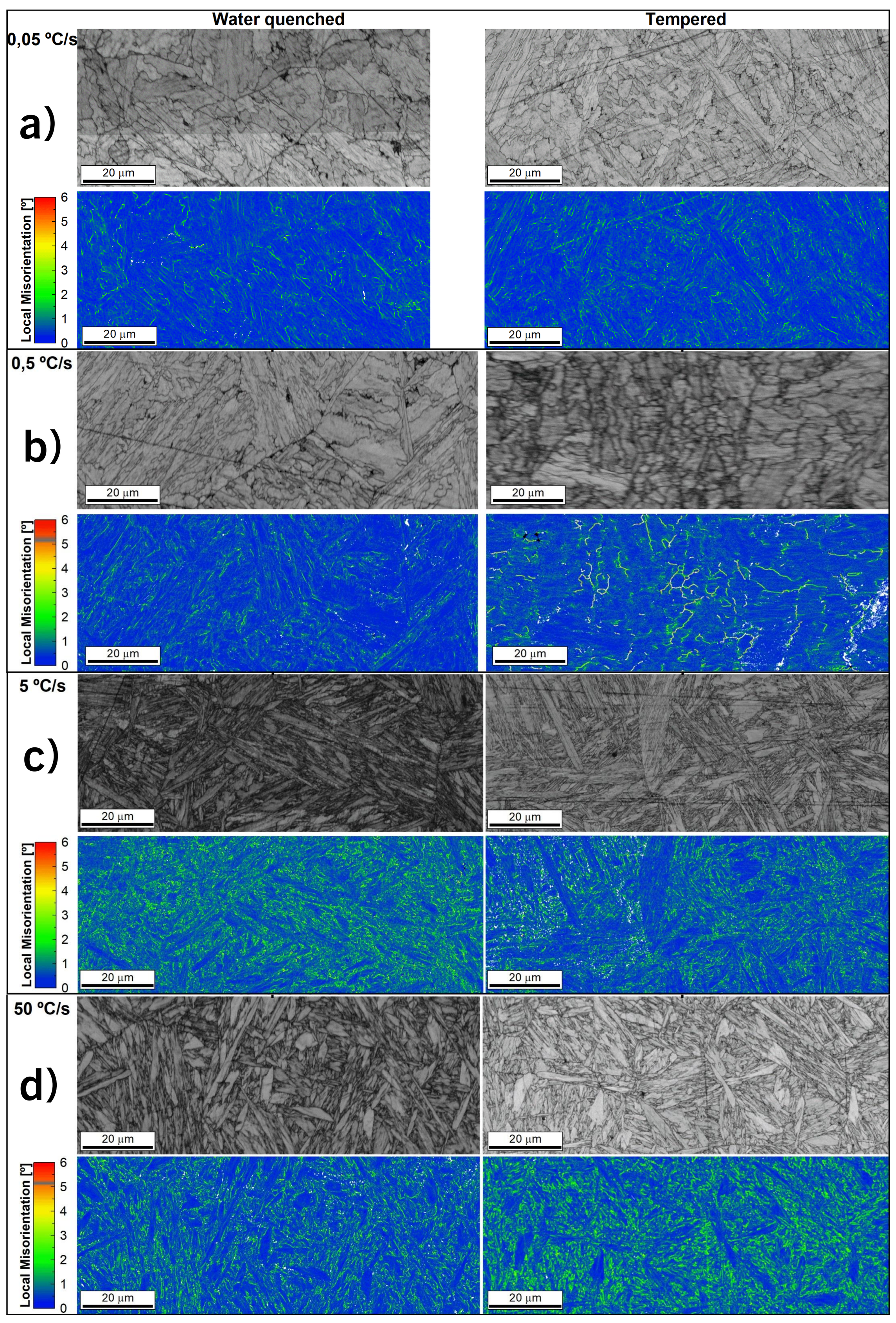


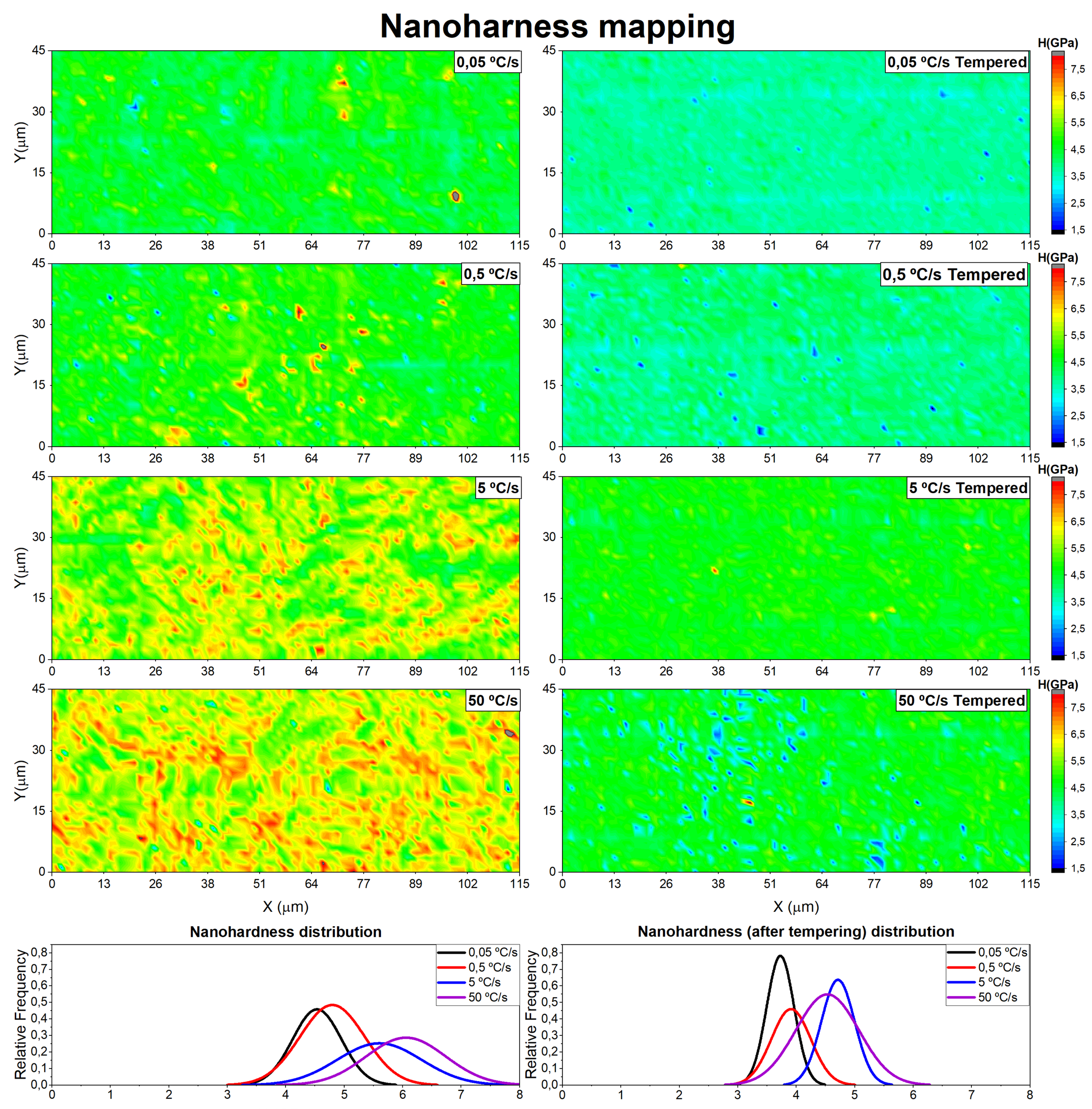
Figure 1. Schematic of the manufacturing process. Numbers 1 and 2 correspond to the analyzed stages of the samples.

Results



Band contrast and Kernel Average Misorientation (KAM) maps for different cooling rates.

- 0.05 ºC/s — Ferritic structure; tempering does not significantly affect average KAM (0.47º → 0.50º), peak stable at 0.35º. Minor changes likely due to local variations, not structural transformations.
- 0.5 ºC/s — Lath-like structures with some coarse grains indicate ferritic-bainitic mix; average KAM increases (0.52º → 0.59º), peak shifts (0.35º → 0.45º).
- 5 ºC/s —Bainitic-martensitic microstructure containing coarse and fine laths; average KAM drops (0.83º → 0.69º), peak lowers (0.55º → 0.45º), reflecting a reduction in lattice distortions due to tempering.
- 50 ºC/s — Finer laths with martensitic-bainitic mix; average KAM rises (0.69º → 0.80º), as well as peak (0.45º → 0.55º); tempering results in low-angle boundaries and carbides.



Nanohardness maps, measured on previously EBSD-scanned areas, can be directly correlated with the local microstructure. Bainite and martensite exhibit higher local nanohardness values compared to ferrite. Tempering leads to a pronounced decrease and homogenization of nanohardness across all conditions, reflecting reduced dislocation density and stress relaxation.

Conclusions

- The increasing cooling rates from 0,05 to 50 ºC/s promote a progressive microstructural transition from ferrite + iron carbides (at 0,05 ºC/s) to bainite (at 0,5 ºC/s), bainite+martensite (at 5 ºC/s) and finally predominantly martensitic microstructure (at 50 ºC/s).
- Average Nanohardness of quenched samples correlate with the microstructural evolution and increases with martensite content, from 4.5 GPa (ferritic, 0.05 ºC/s) to 6.1 GPa (martensitic, 50 ºC/s). With intermediate values for ferritic-bainitic (4.8 GPa, 0.5 ºC/s) and bainitic-martensitic (5.8 GPa, 5 ºC/s) microstructures. Tempering uniformly reduces average nanohardness to 3.7 GPa (ferritic), 3.9 GPa (ferritic-bainitic), 4.7 GPa (bainitic-martensitic), and 4.5 GPa (martensitic), reflecting microstructural softening and homogenization.
- The influence of tempering on KAM depends on the microstructure: No effect in ferritic regions, a slight increase in ferritic-bainitic (recovery, low-angle boundaries), a decrease in bainitic-martensitic (stress relaxation), and an increase in martensitic (carbide precipitation, substructure formation).

Acknowledgements

This project has received funding from the European Union under Grant Agreement 101091912.

Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the European Health and Digital Agency. The granting authority cannot be held responsible for them.

Funded by the European Union