

# Metallography of a Modern Pattern-Welded Steel Knife Blade

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Fig. 1 – Forge-welding the layers together.



Fig. 2 – An example of a finished pattern-welded steel knife etched with 12% FeCl<sub>3</sub>. Forged by the author.



Fig. 3 – Heating the material in preparation for forging a knife blade.

## BACKGROUND INFORMATION

- Pattern-welded steel dates back to Viking times.
- The material is made by forge-welding alternating layers of two different steels together. (Fig. 1)
- The material is then heated in a coal forge (Fig. 3) and hand forged into a knife which is then etched to reveal the pattern. (Fig. 2)

## OBJECTIVES

### Understanding Art through Science

- Determine how the carbon and nickel content in the two layer types change during pattern-welding.
- Determine the effect of diffusion on the microstructure of the finished knife.

## PROCEDURE

- The starting materials were W-2 tool steel and ASME AS-203E pressure vessel steel. (See Table 1 for compositions)
- Samples were removed after each step of pattern-welding yielding 4, 16, 32, 64, 128, and 256 layer samples.
- Samples were also taken from a 256 layer heat-treated blade.
- Light optical microscopy was used to determine qualitatively the extent of carbon diffusion, while nickel diffusion in the final blade was examined using an electron microprobe.

## RESULTS AND DISCUSSION

### Carbon Diffusion

- Carbon was expected to diffuse from the high carbon W-2 layers to the low carbon 203E layers.
- The carbon content is indicated by the relative amounts of pearlite (dark-colored carbon-rich constituent) and ferrite (white low-carbon phase in Figs. 4 -11).
  - 4 layer sample (Figs. 4 and 5)
    - 203E layers consist mainly of ferrite with increasing amounts of pearlite near the interfaces.
  - 8 layer sample (Figs. 6 and 7)
    - 203 E layers consist largely of pearlite but show ferrite outlining prior austenitic grains.
  - 16 layer sample (Figs. 8 and 9)
    - Both layers show a uniform pearlite distribution, indicating a uniform carbon concentration.
  - 256 layer sample (Figs. 10 and 11)
    - Pearlite distribution remains uniform.

### Nickel diffusion

- Nickel diffusion was determined by a wavelength dispersive spectroscopy line trace using an electron microprobe.
- The results (Fig. 12) show that no appreciable nickel diffusion occurs during manufacture.

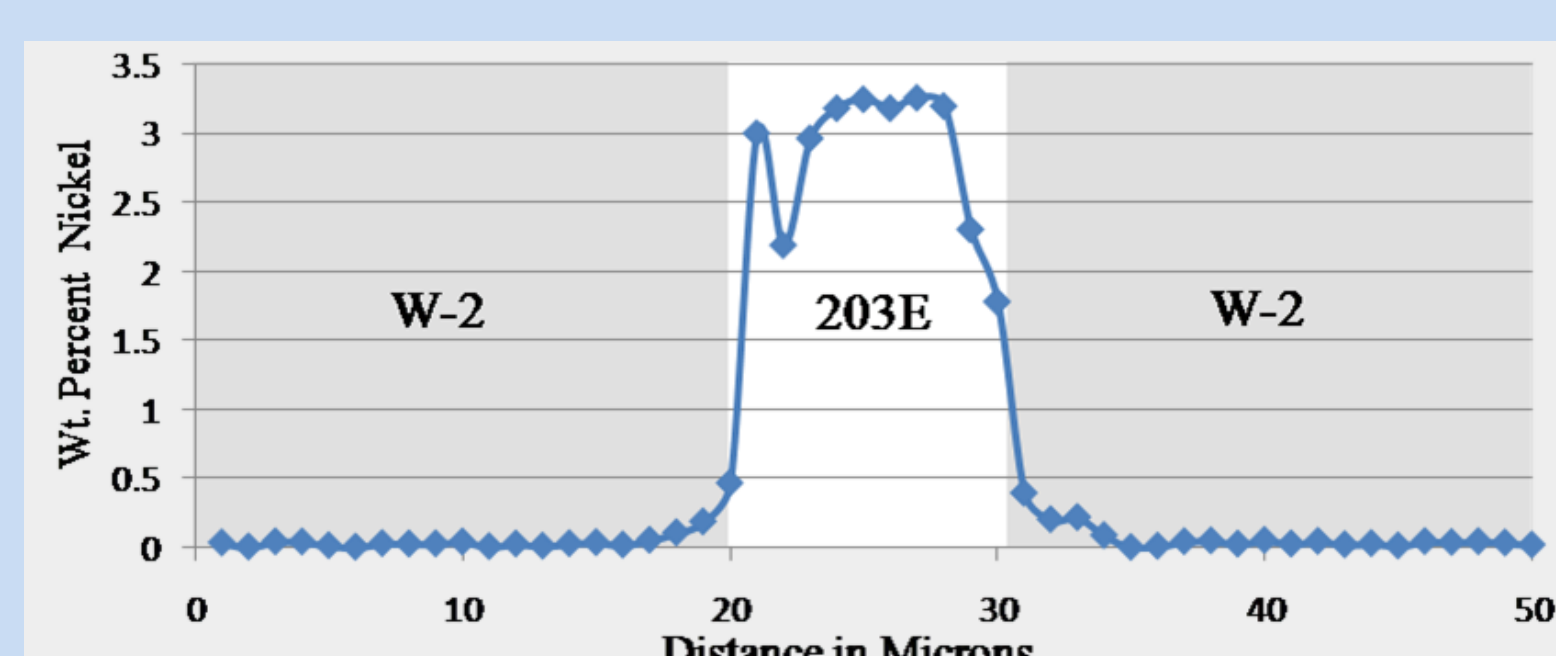


Fig. 12 - Microprobe data showing the nickel distribution across three layers in the edge of the heat-treated knife blade.

Table 1 – Chemical compositions of starting materials AISI W-2 and ASME 203E.

Grade	C	Mn	Ni	V	Fe
W2	1.07 wt%	0.46 wt%	0.03 wt%	0.19 wt%	balance
203E	0.14 wt%	0.58 wt%	3.43 wt%	---	balance

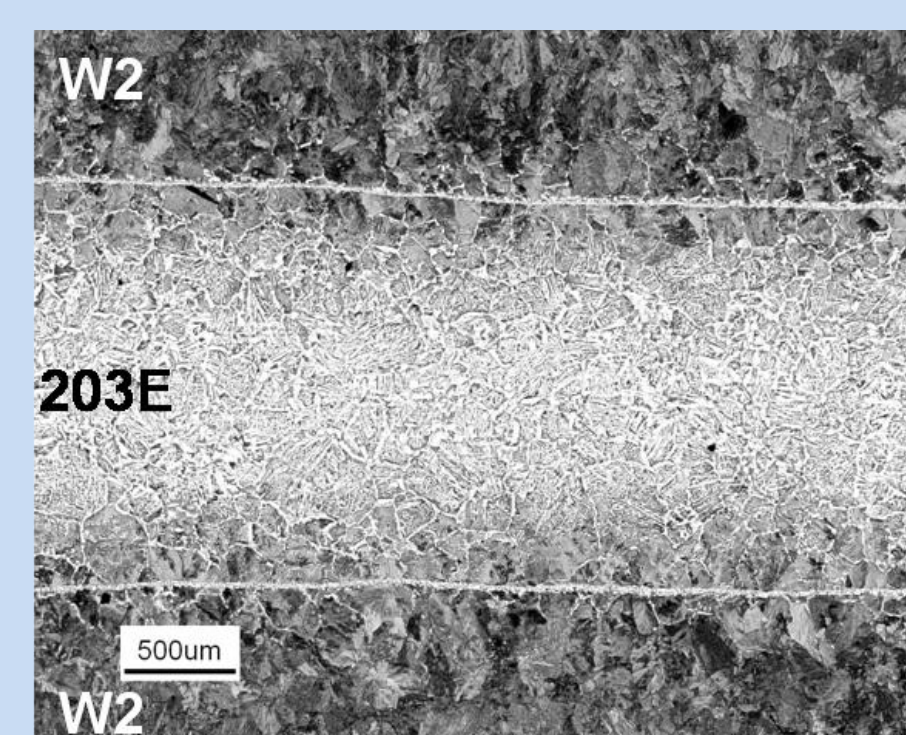


Fig. 4 – Annealed 4 layer sample. Etched in 4% picral.

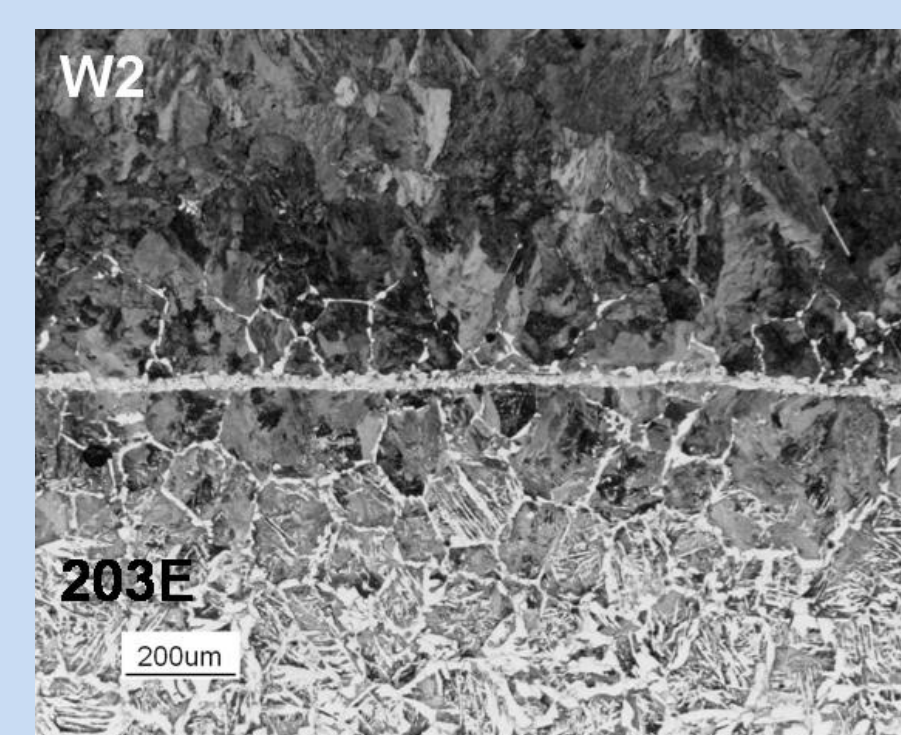


Fig. 5 – Interface in 4 layer sample. Etched in 4% picral.

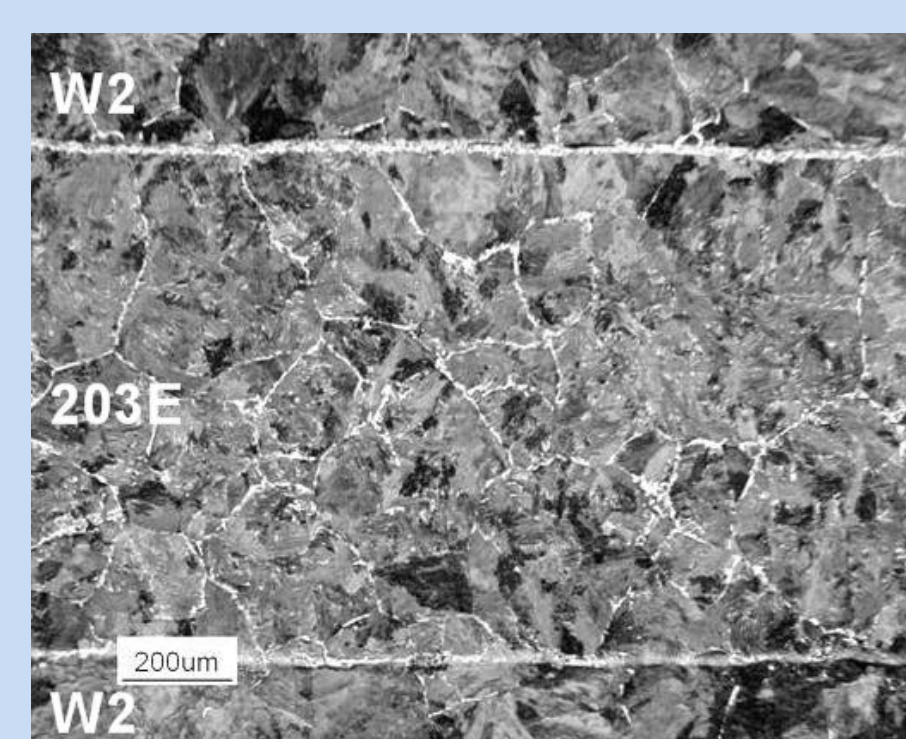


Fig. 6 – Annealed 8 layer sample. Etched in 4% picral.

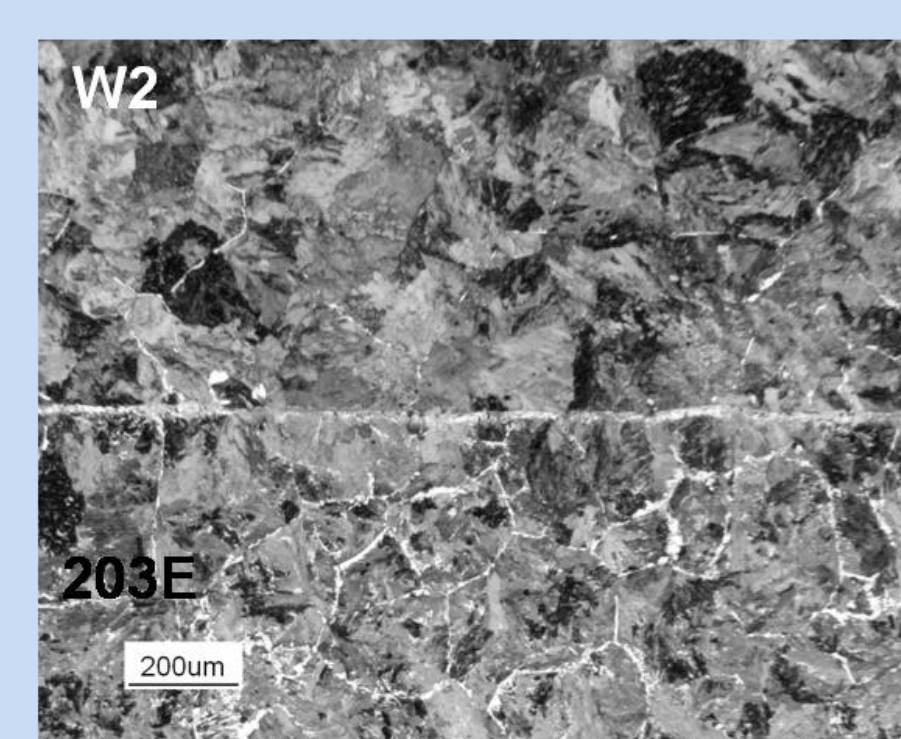


Fig. 7 – Interface in 8 layer sample. Etched in 4% picral.

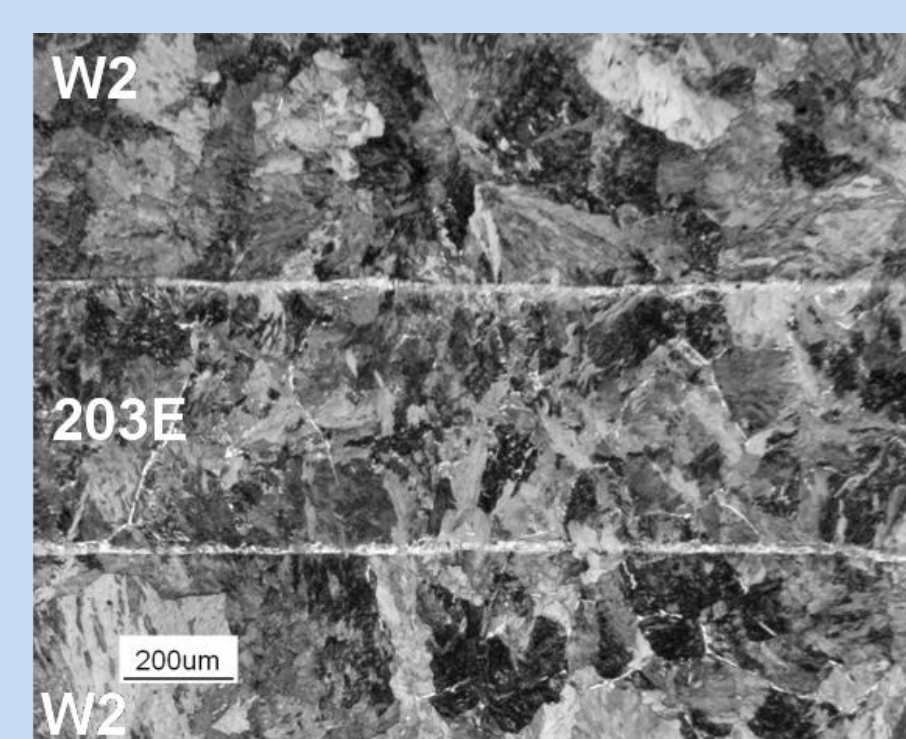


Fig. 8 – Annealed 16 layer sample. Etched in 4% picral.

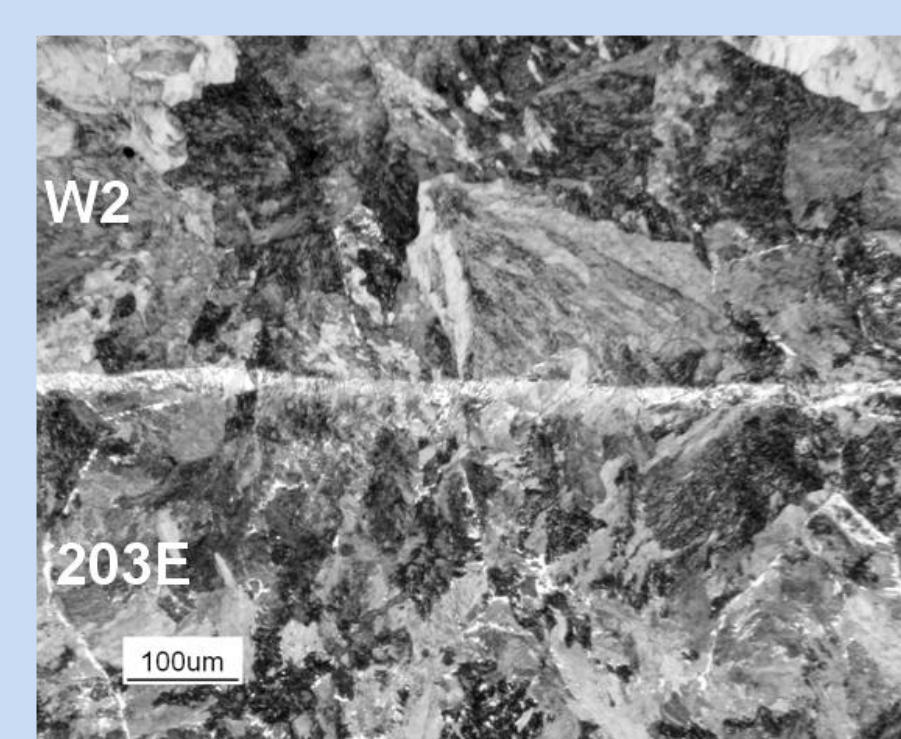


Fig. 9 – Interface in 16 layer sample. Etched in 4% picral.

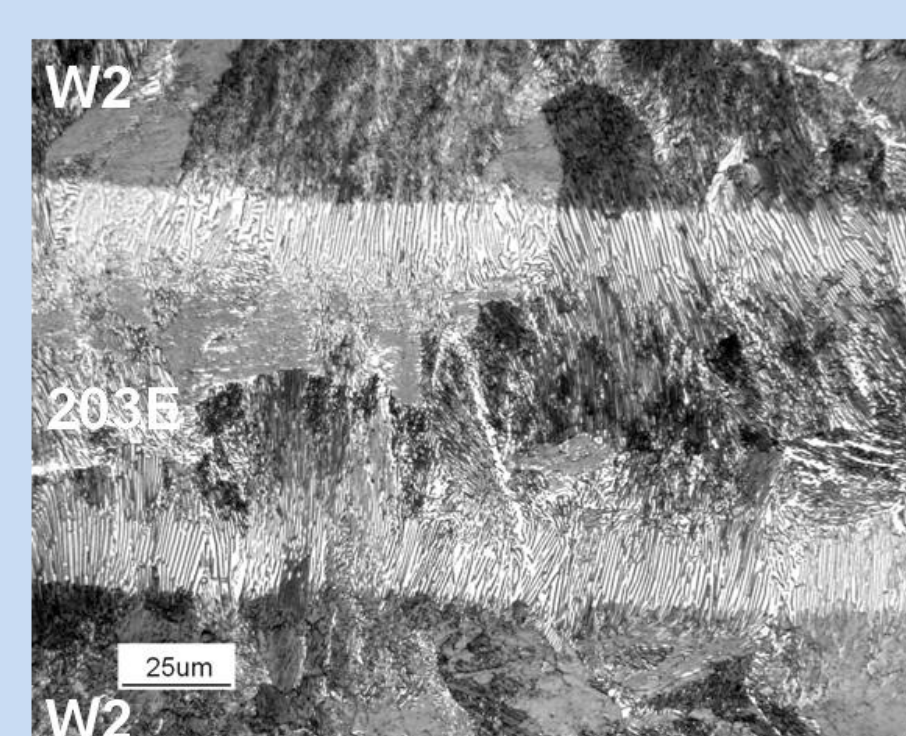


Fig. 10 – Annealed 256 layer sample. Etched in 4% picral.



Fig. 11 – Interface in 256 layer sample. Etched in 4% picral.

## Blade Microstructure

### Edge (Fig. 13)

- Both the W-2 and 203E are martensitic.

### Spine (Fig. 13)

- W-2 is a mixture of martensite and fine pearlite.
- 203E is martensitic.

This difference in microstructure between the layers in the edge and the spine of the blade results from the different cooling rates (the thin edge cools faster).

The difference in the microstructure of the W2 and 203E in the spine of the blade results from the inhomogeneous distribution of nickel and its effect on phase transformation temperatures.

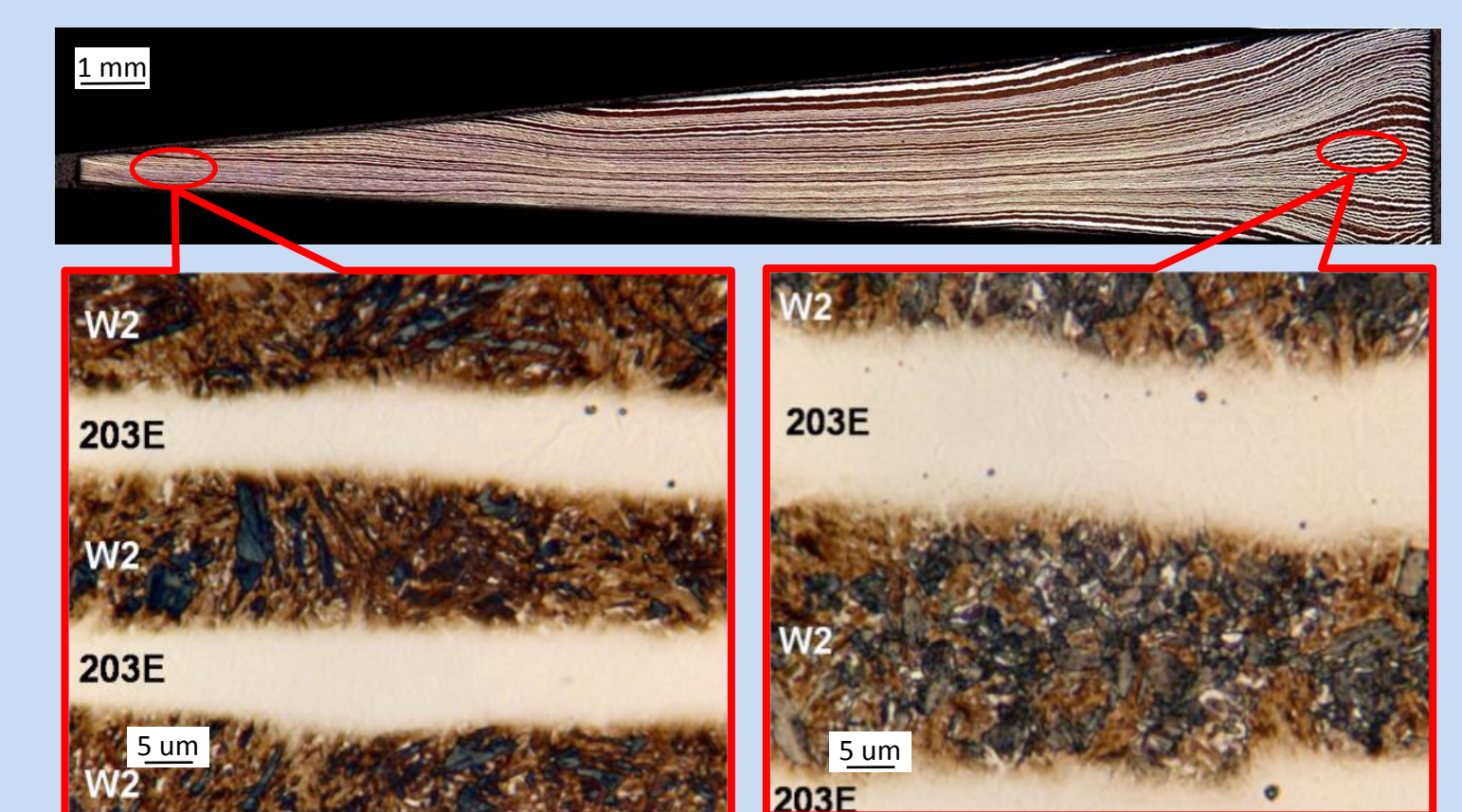


Fig. 13 – Cross section of the heat-treated blade etched in 12% Sodium Metabisulfite.

## CONCLUSIONS

- Carbon diffusion occurs rapidly during the manufacture of pattern-welded steel.
- The carbon content in the finished material is homogeneous.
- Nickel diffusion does not occur to any appreciable extent (each layer retains its original nickel concentration).
- Due to the differential cooling rates and the nickel-induced difference in hardenability of the two layer types, a finished pattern-welded steel blade displays a complex and beautiful structure.

## ACKNOWLEDGEMENTS

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