Calculating phase transformations in duplex stainless steels using computational thermodynamics

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Acknowledgment:
- The member research consortium MRC Stainless at Swerea KIMAB AB
- Outokumpu Stainless AB
- AB Sandvik Materials Technology
- KTH Royal Institute of Technology
- Jernkontoret - The Swedish Steel Producers' Association
- Thermo-Calc Software AB

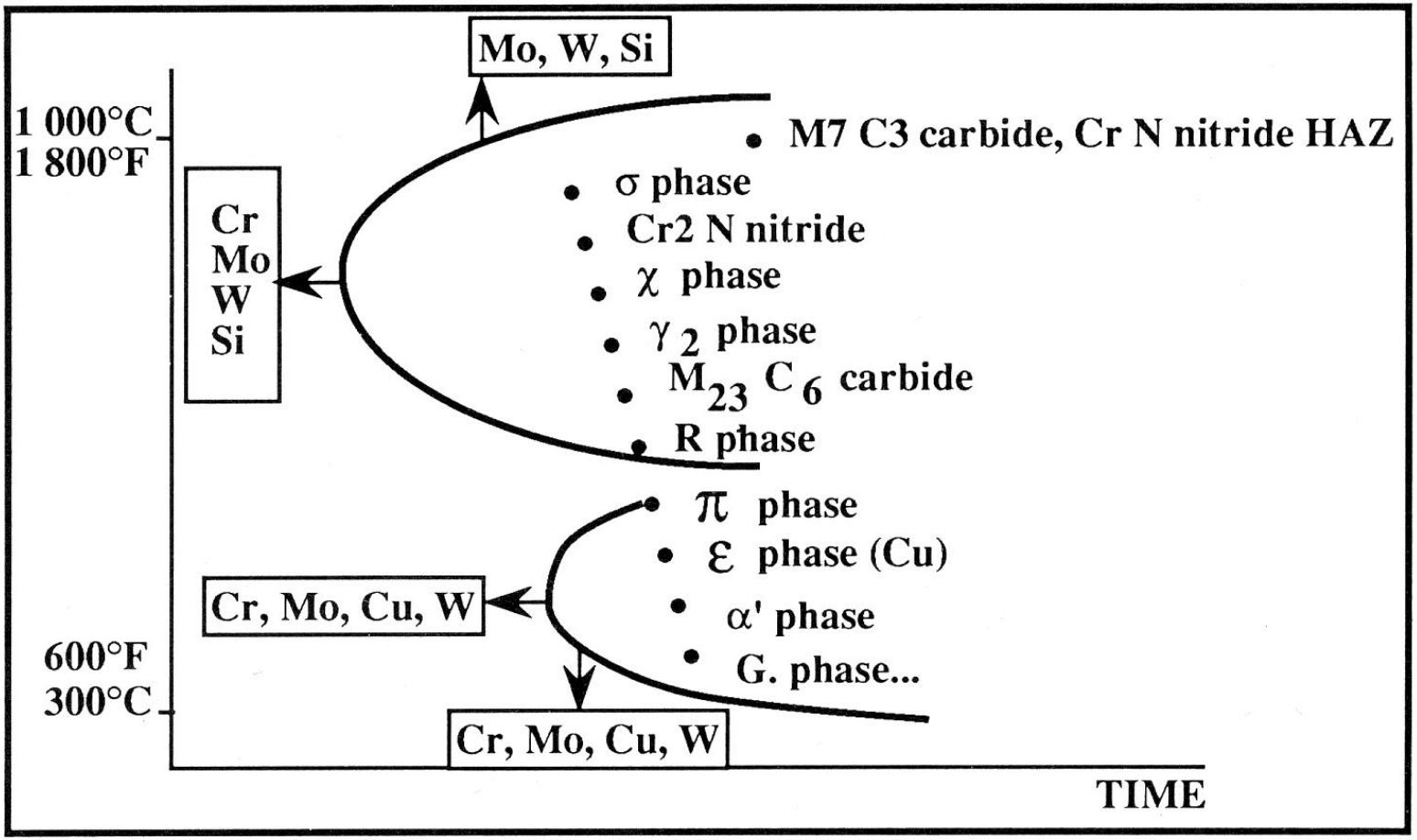
Duplex stainless steels:

- Consist of about equal amounts of ferrite and austenite

Lean: LDX 2101®	Fe-5Mn-**21.5Cr-1.5Ni**-0.3Mo-0.22N
Standard: 2205	Fe-**22Cr-5.5Ni**-3Mo-0.17N
Super: 2507	Fe-**25Cr-7Ni**-4Mo-0.27N
Hyper: SAF 3207 HD™	Fe-**32Cr-7Ni**-3.5Mo-0.50N

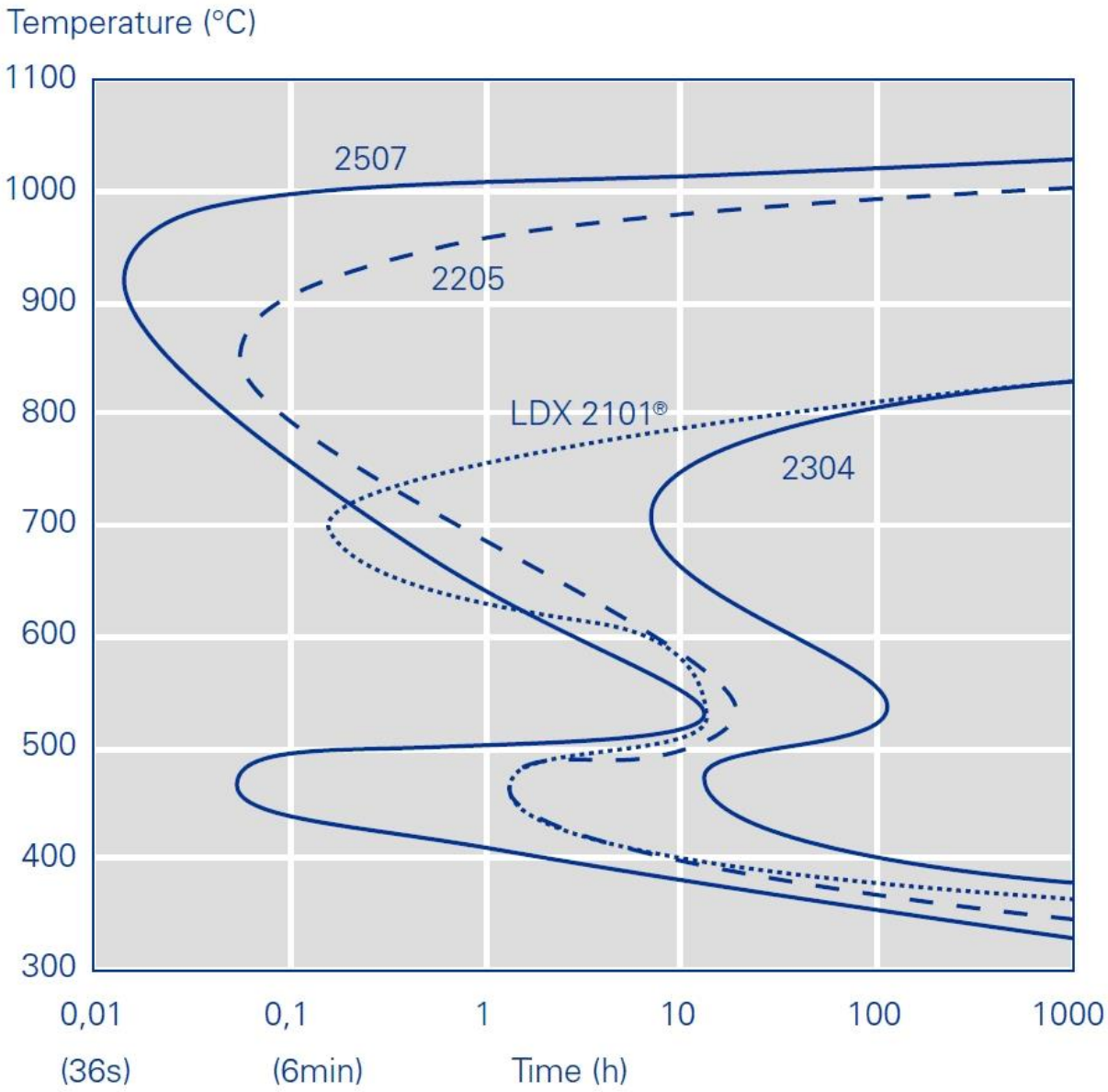
- Doubled strength, compared to austenitics
- Excellent corrosion resistance
- Good weldability properties
- Low Ni, compared to austenitics, i.e. favourable cost
- Lean duplex: Ni partly substituted by Mn+N

☺ Cr+Mo = Corrosion resistance
☹ Cr+Mo = Intermetallic phases



J. Charles, Proc. Duplex Stainless Steels ´91, Beaune, France, 1 (1991)

Schematic TTP (time to-precipitation) diagram



From Outokumpu Stainless AB, 50 % toughness loss

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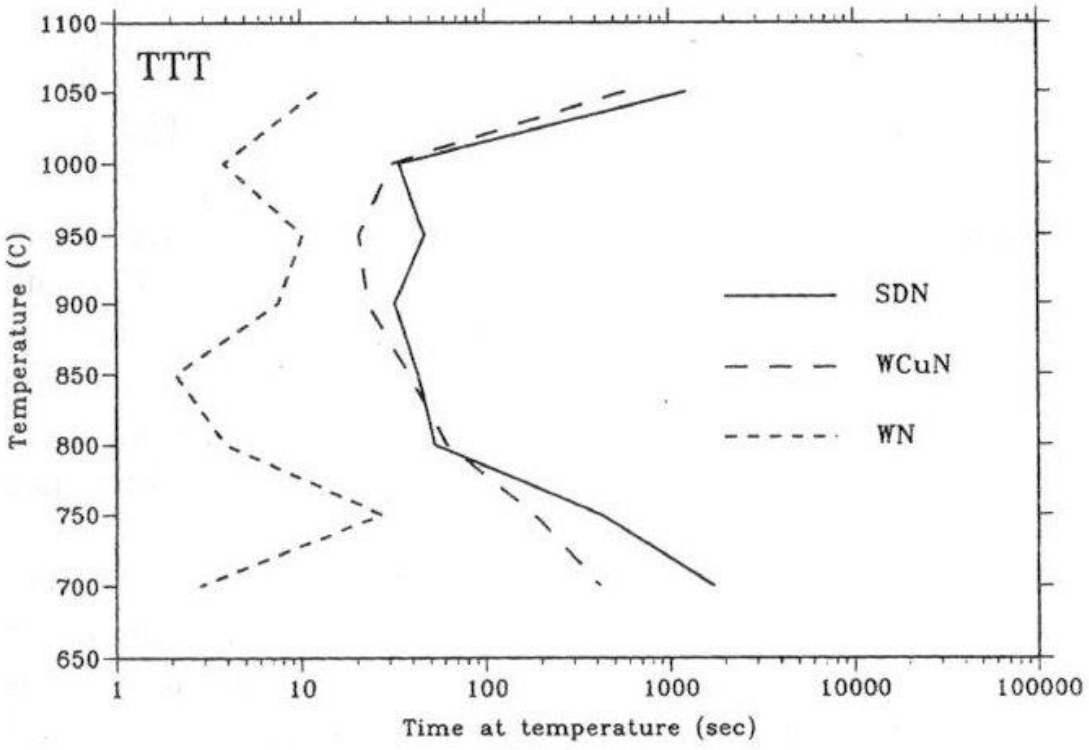
Chemical compositions [wt.-%]:

	C	Si	Mn	**Cr**	**Ni**	**Mo**	**N**	**Cu**	**W**
SDN	0.034	0.75	0.72	**25.59**	**9.26**	**3.79**	**0.25**	0.09	<0.003
WCuN	0.038	0.38	0.93	**25.47**	**9.20**	**3.60**	**0.23**	**0.62**	**0.92**
WN	0.046	0.69	1.34	**25.67**	**9.60**	**3.09**	**0.24**	0.09	**2.34**



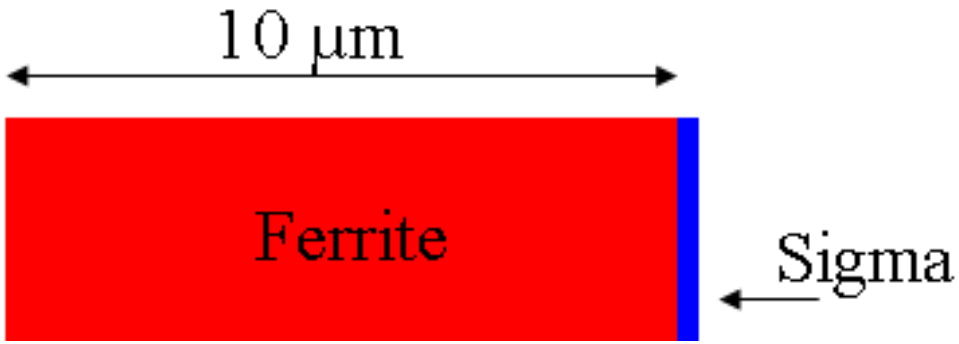
MMA welds:
- Isothermal heat treatments
- Optical microscopy
- SEM
- Point counting

TTT diagram showing C-curves representing 1 % of intermetallic phase.

J-O Nilsson et al., Met. and Mat. Trans. 27A (1996)

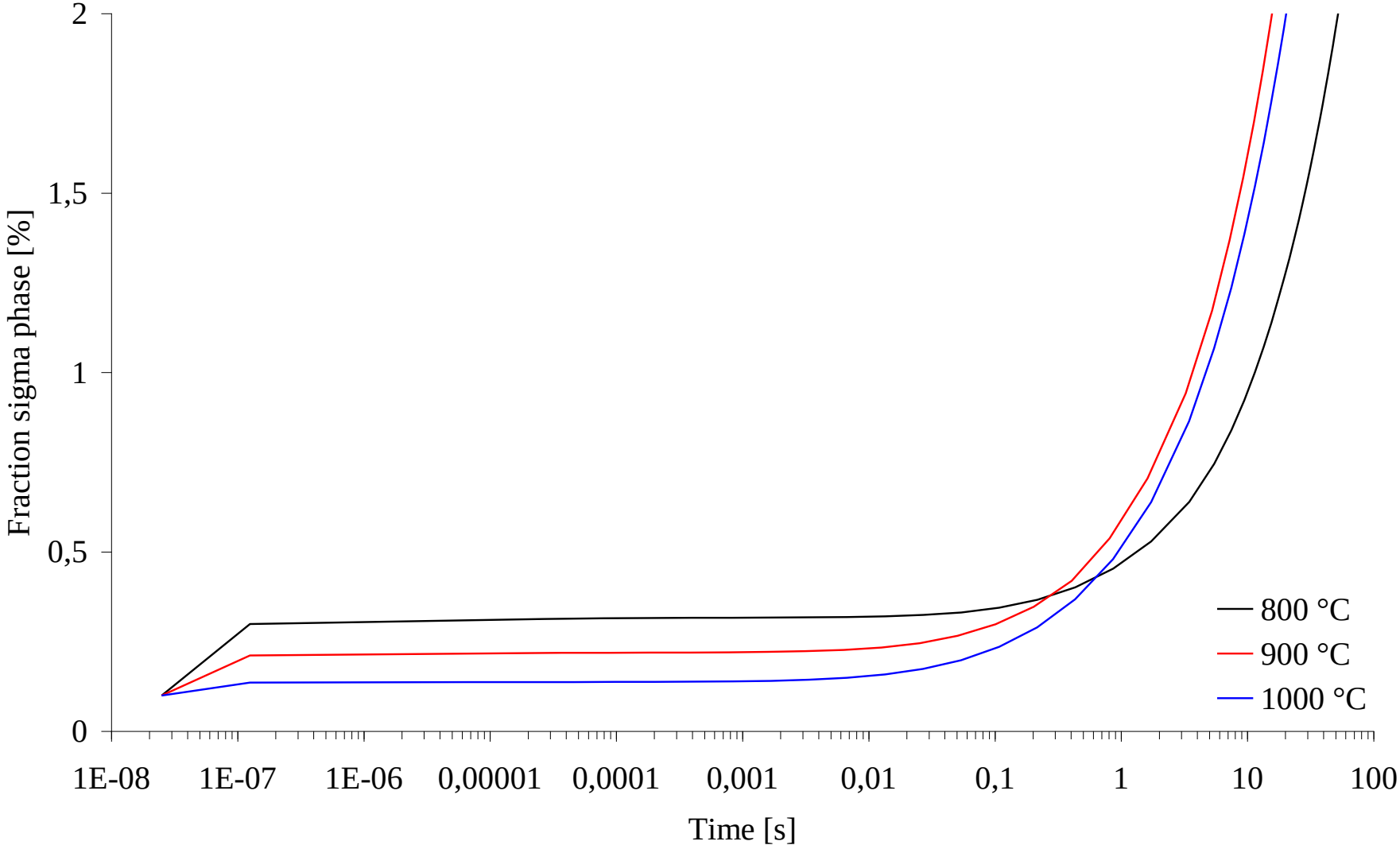
Simplified chemical compositions [wt.-%]:

	C	Si	Mn	Cr	Ni	Mo	N	Cu	W
SDN	-	-	-	25.59	9.35	3.79	0.284	-	-
WCuN	-	-	-	25.47	9.82	3.60	0.268	-	0.92
WN	-	-	-	25.67	9.69	3.09	0.286	-	2.34



Approach:

- Omit the austenite, only ferrite and austenite
- Simplifications: Si & Mn omitted; C → N and Cu → Ni
- Thermo-Calc: Calculate the ferrite composition at 1100 °C (1150 °C WN)
- 10 µm ferrite → DICTRA; TCFE6 & MOB1
- **Time to grow 1 % sigma phase**



SDN: Growth of sigma phase

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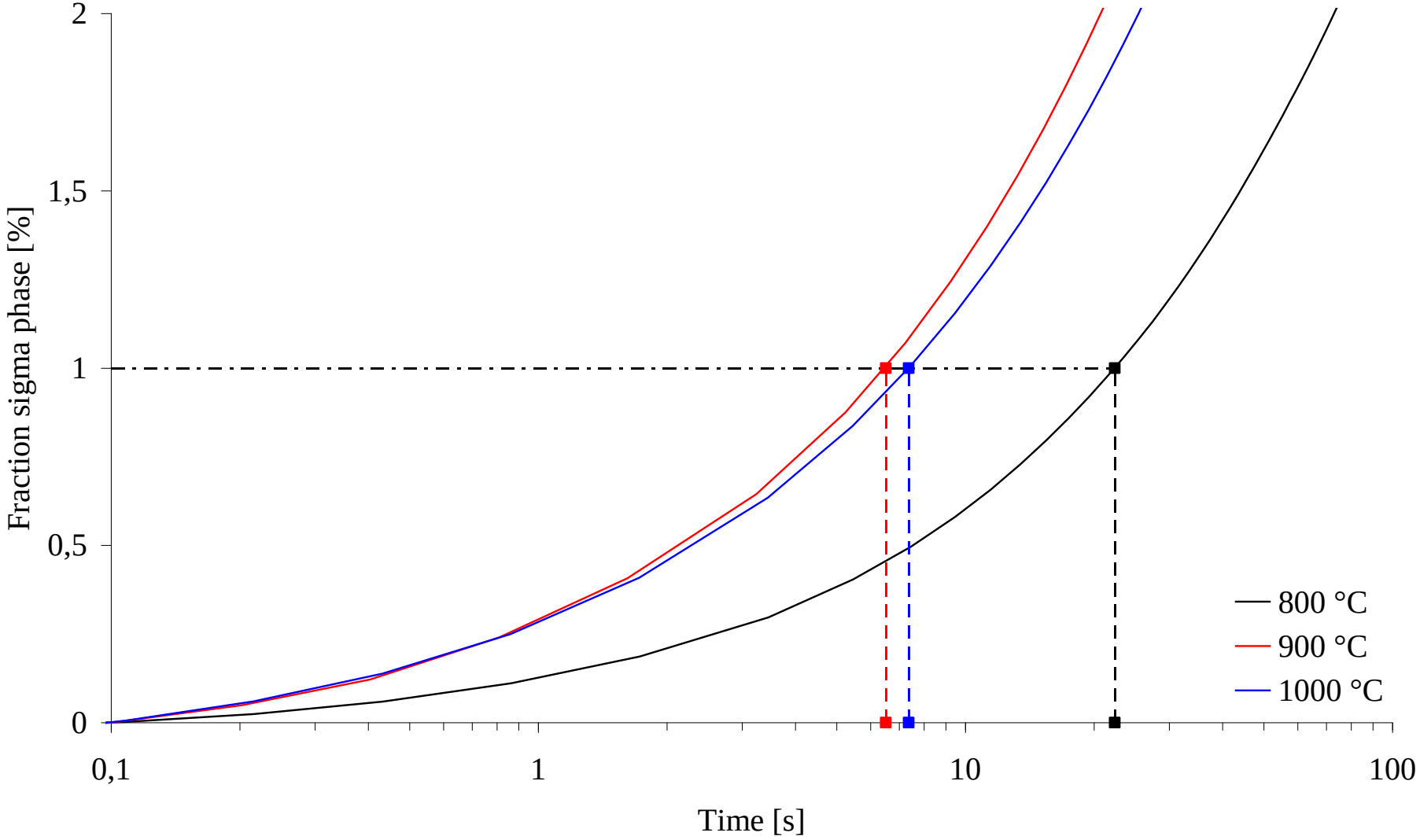

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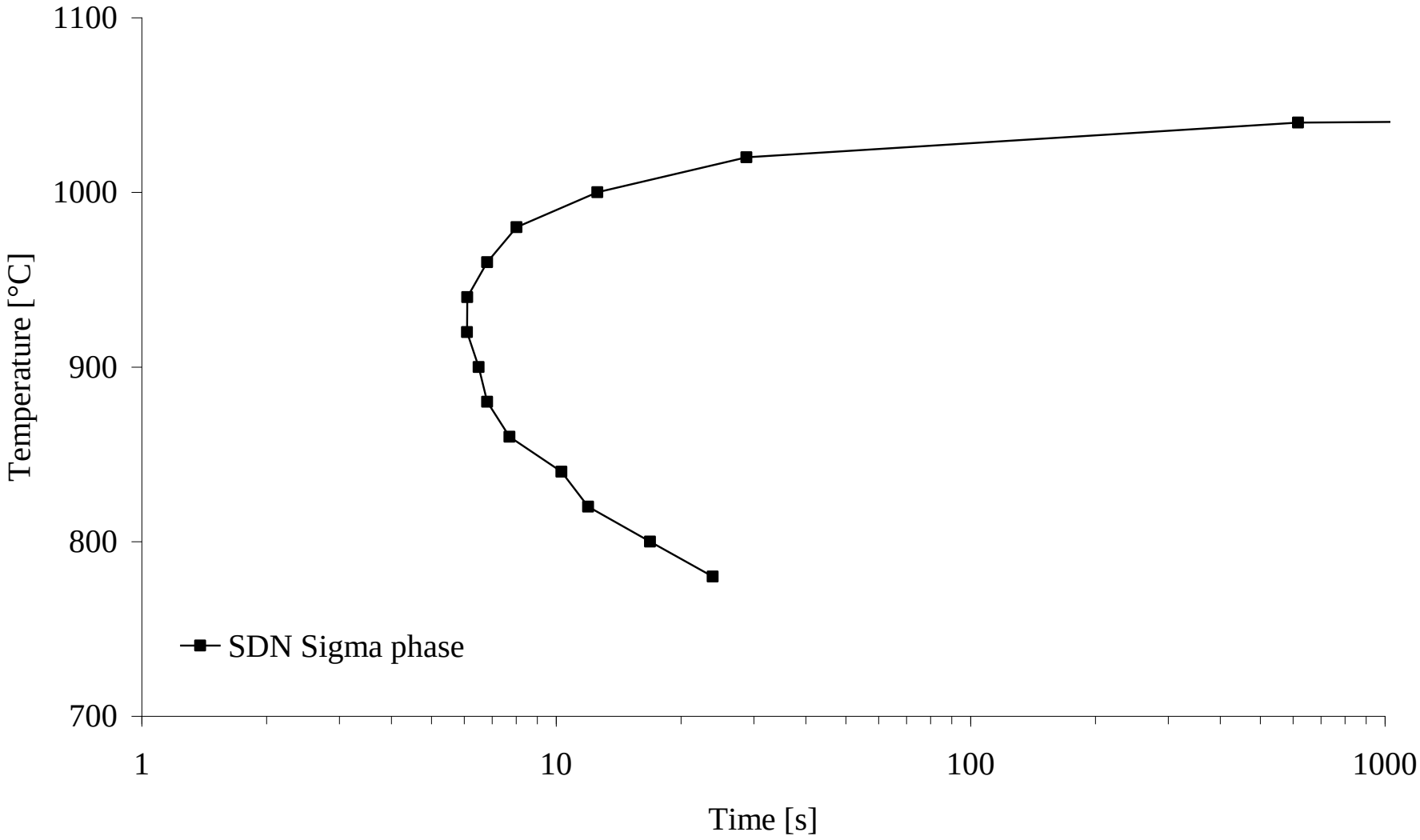

SDN: TTT-diagram

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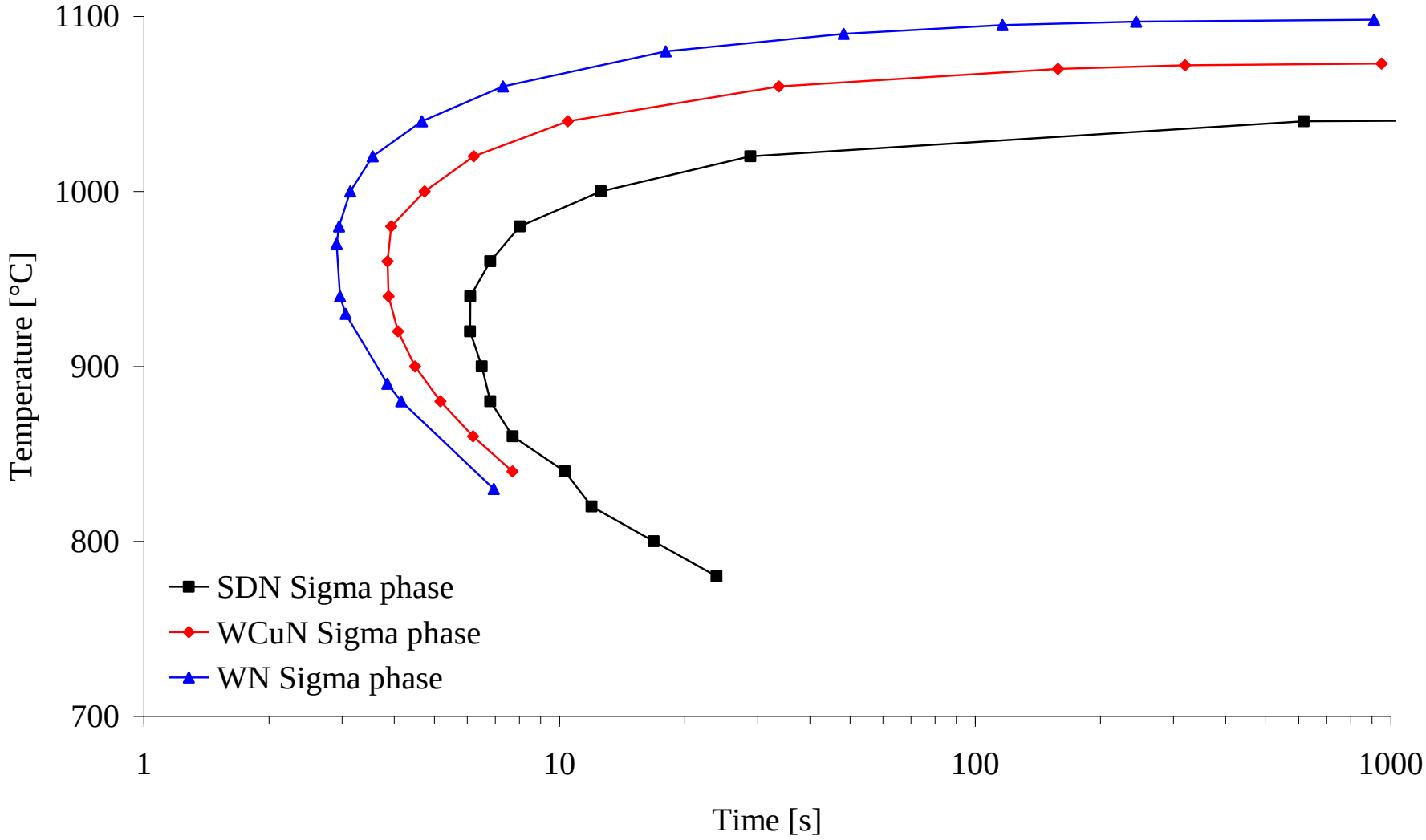

SDN, WCuN & WN: TTT-diagrams

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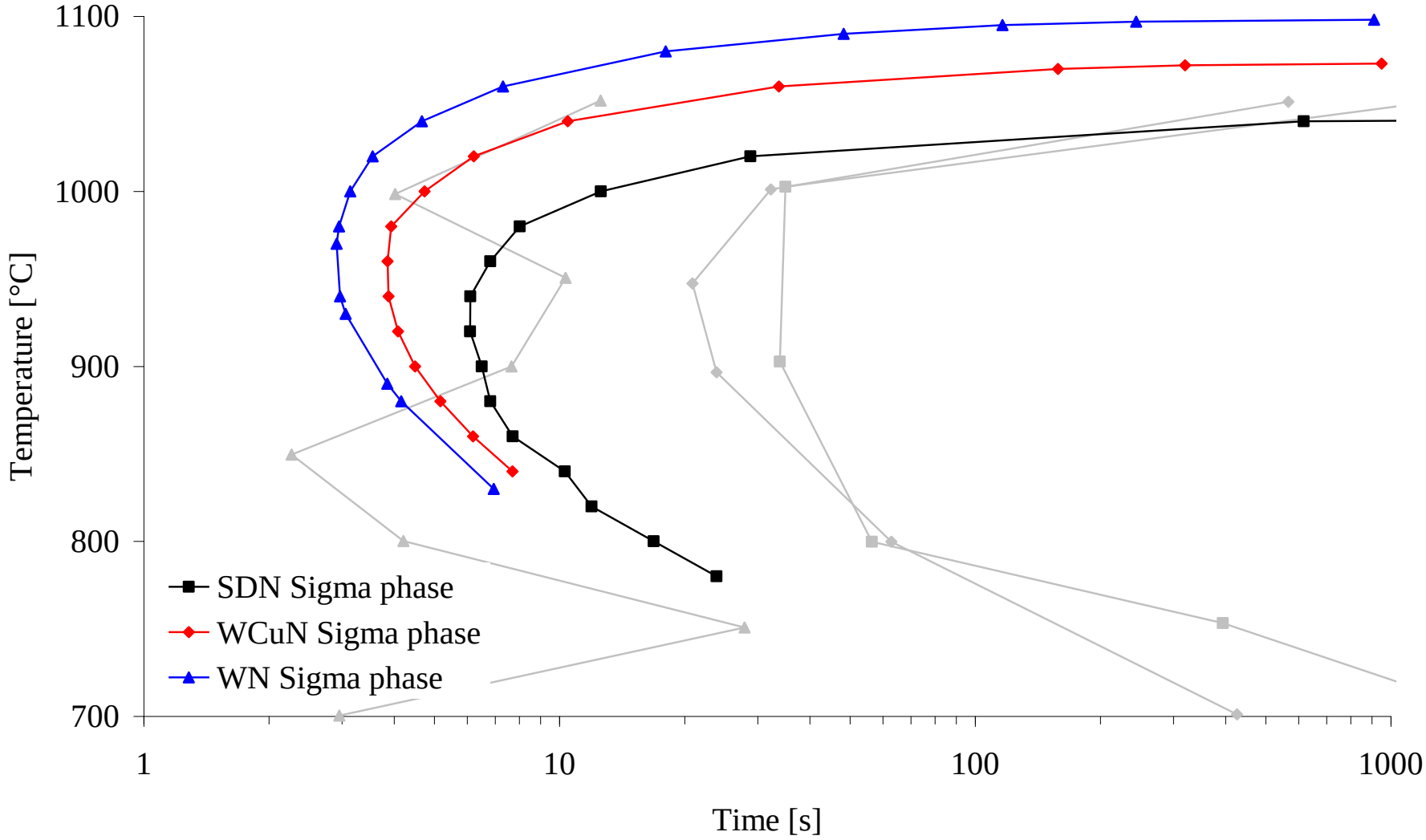

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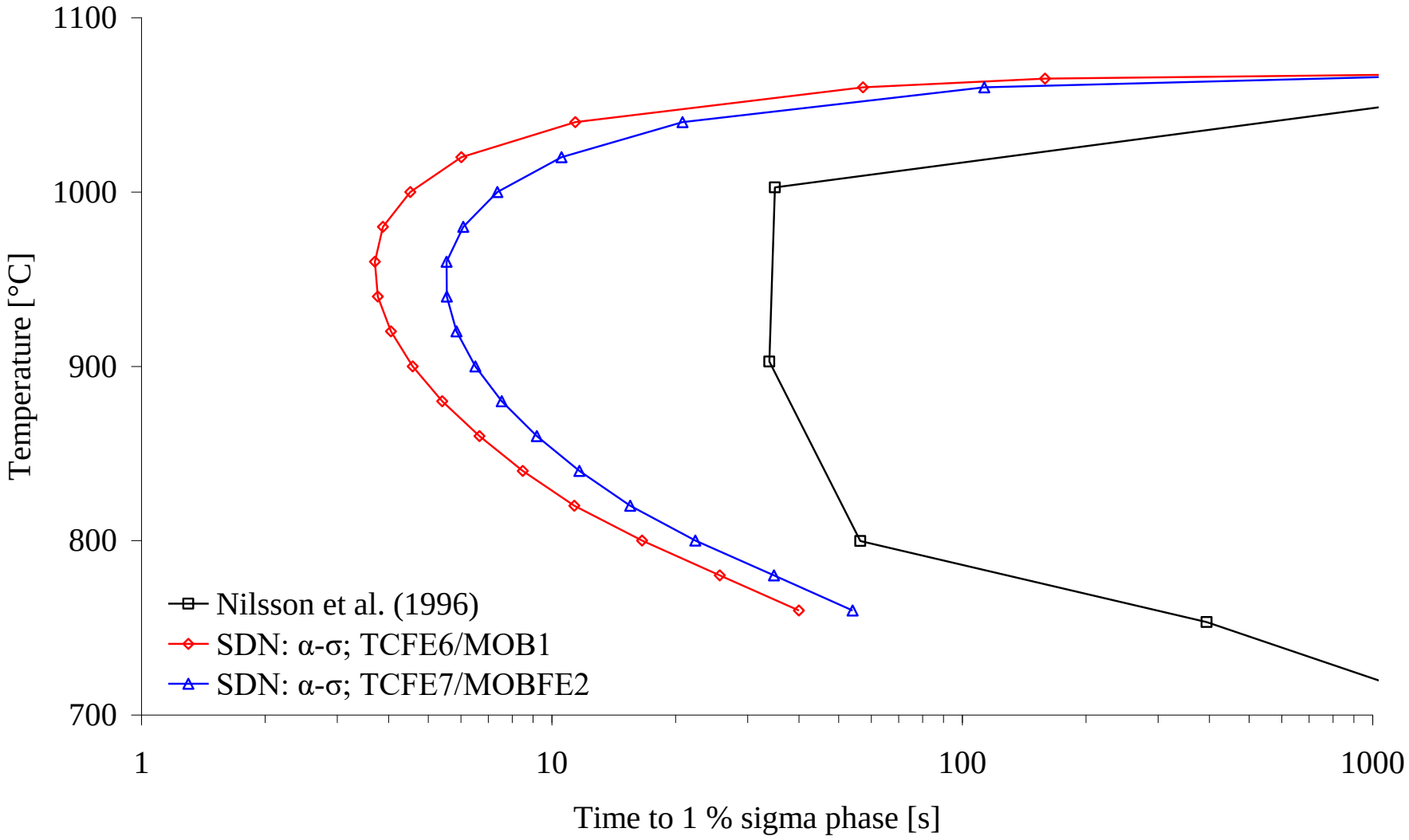

SDN: TCFE6/MOB1 & TCFE7/MOBFE2

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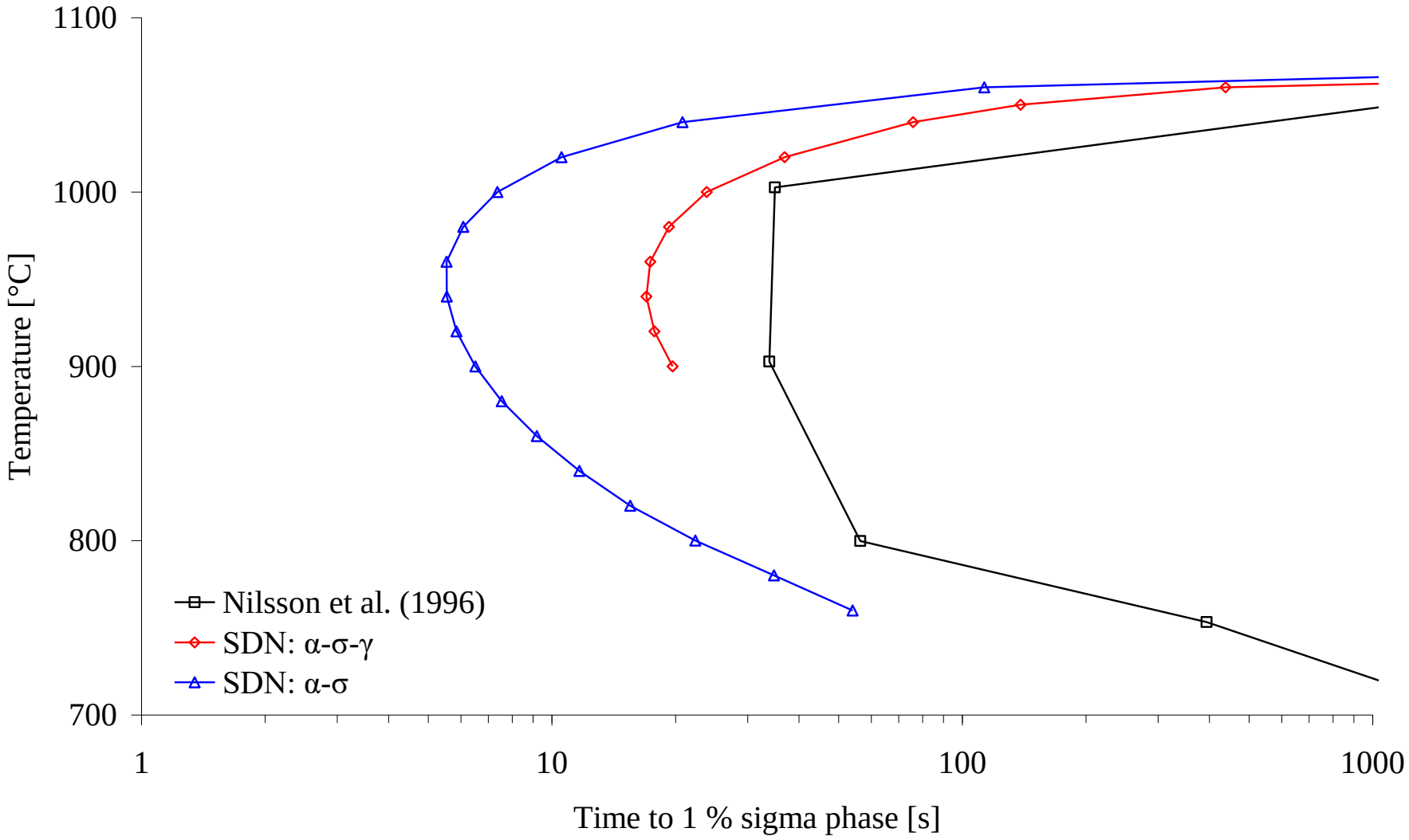
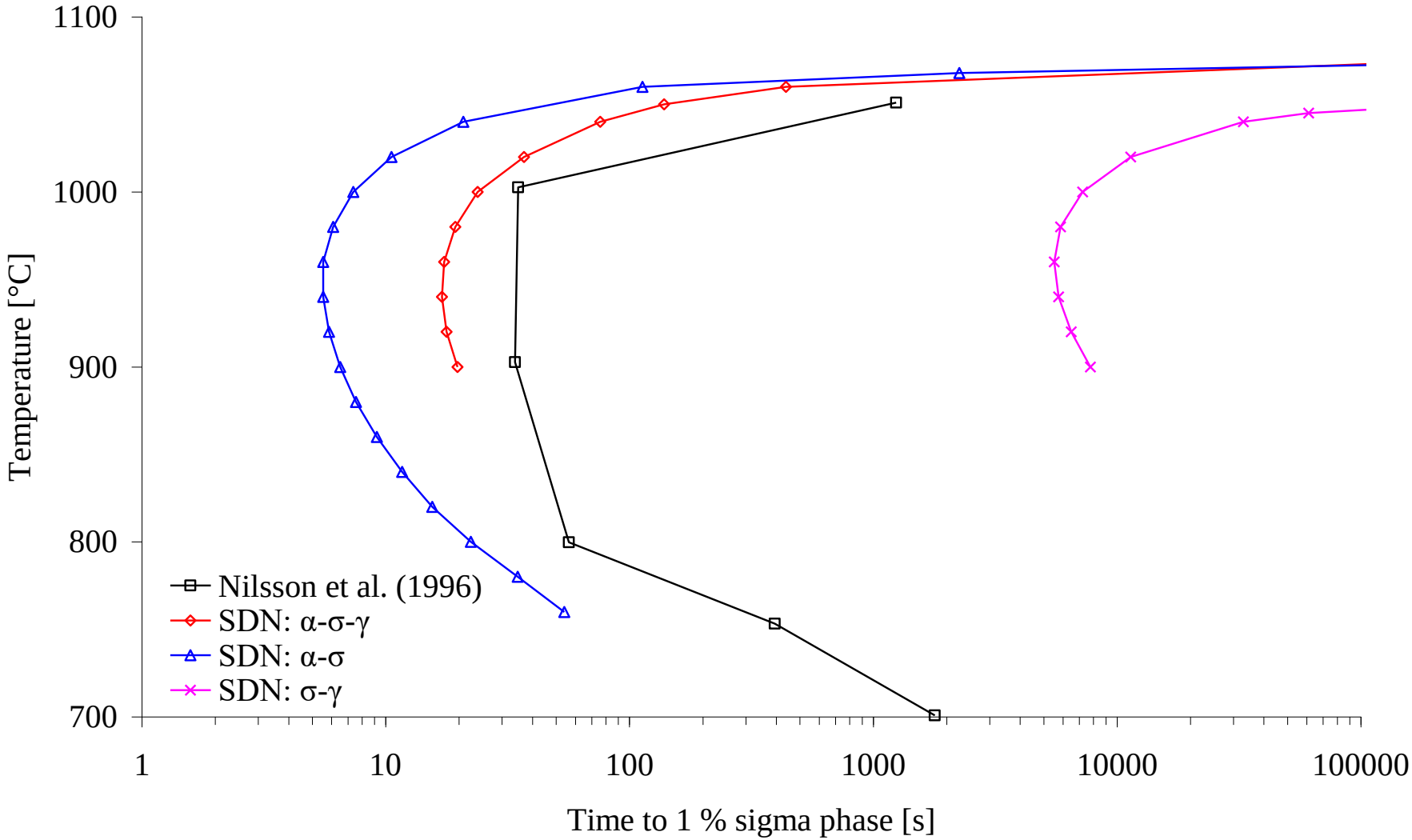
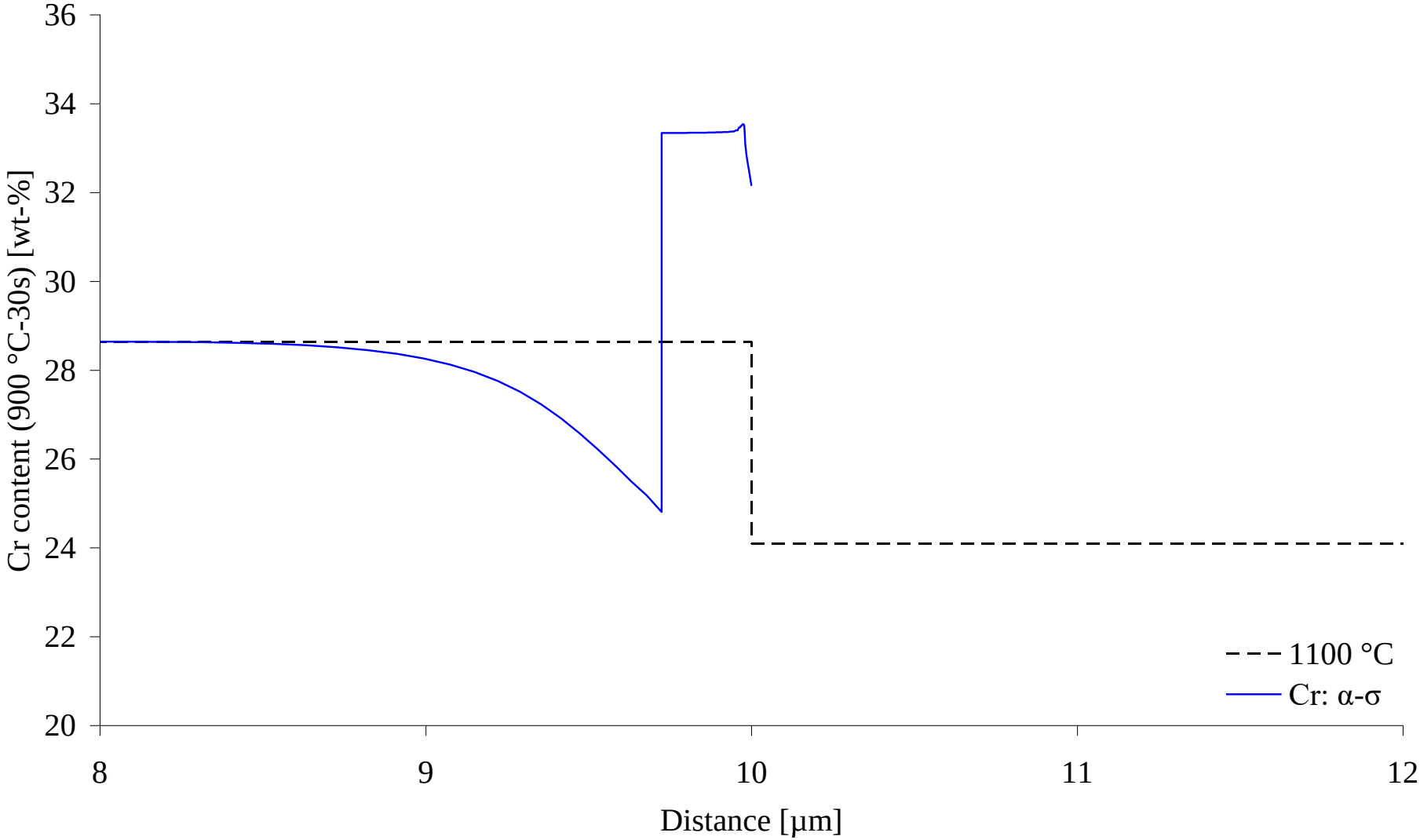


SDN: α-σ-γ versus α-σ



SDN: α-σ-γ & α-σ versus σ-γ



SDN: Depleted zones, 900 °C-30 s

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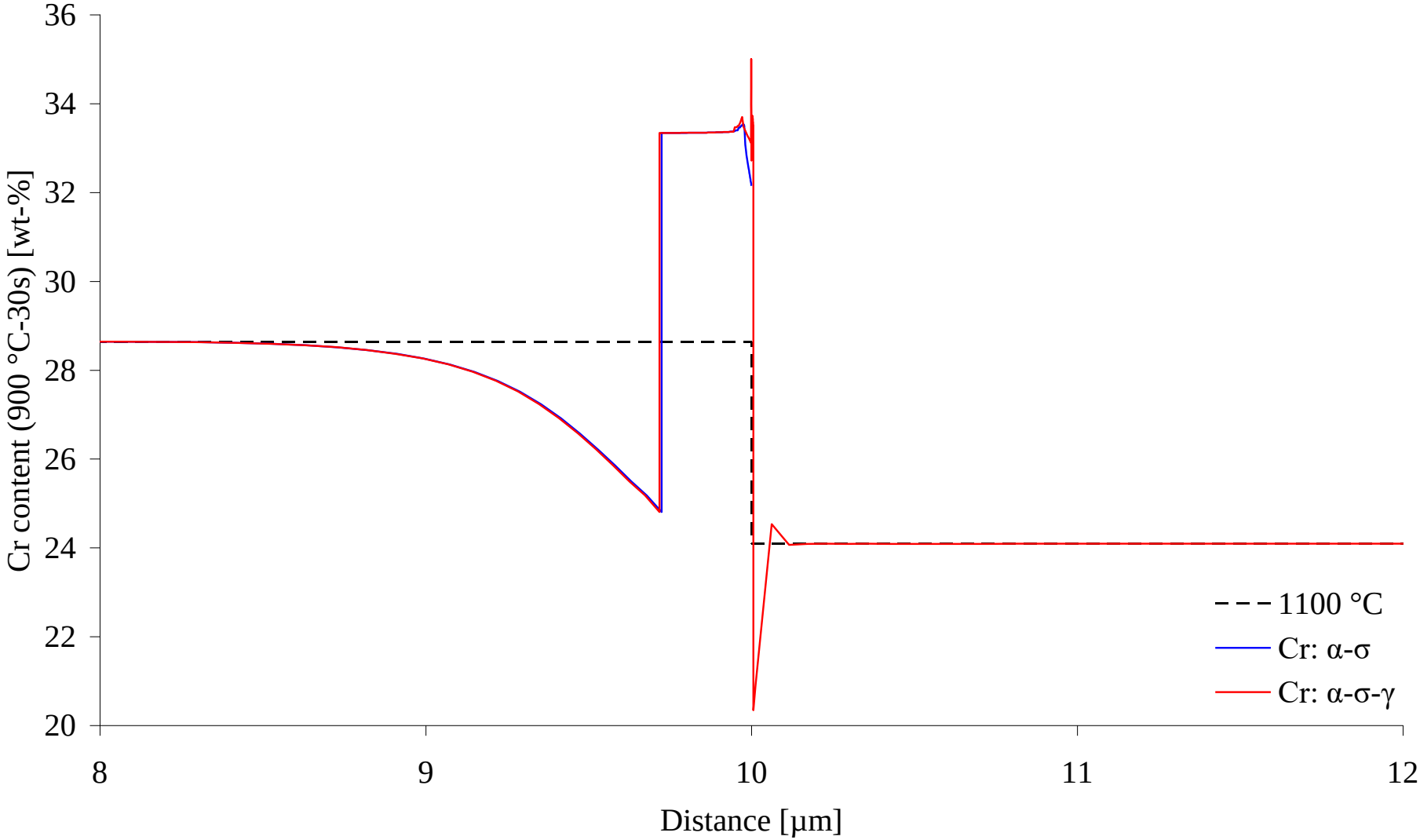

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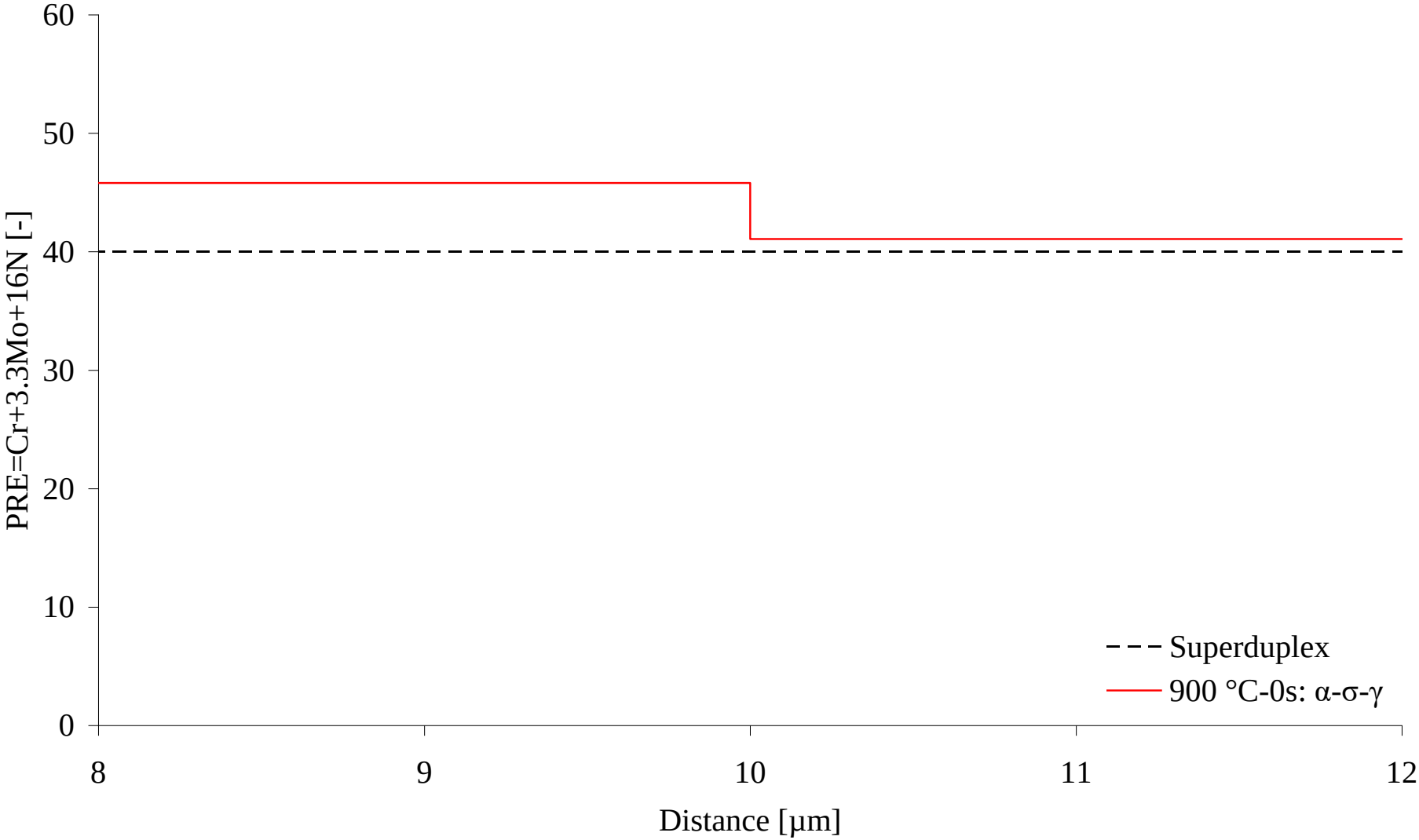

SDN: Pitting resistance equivalent PRE=Cr+3.3Mo+16N

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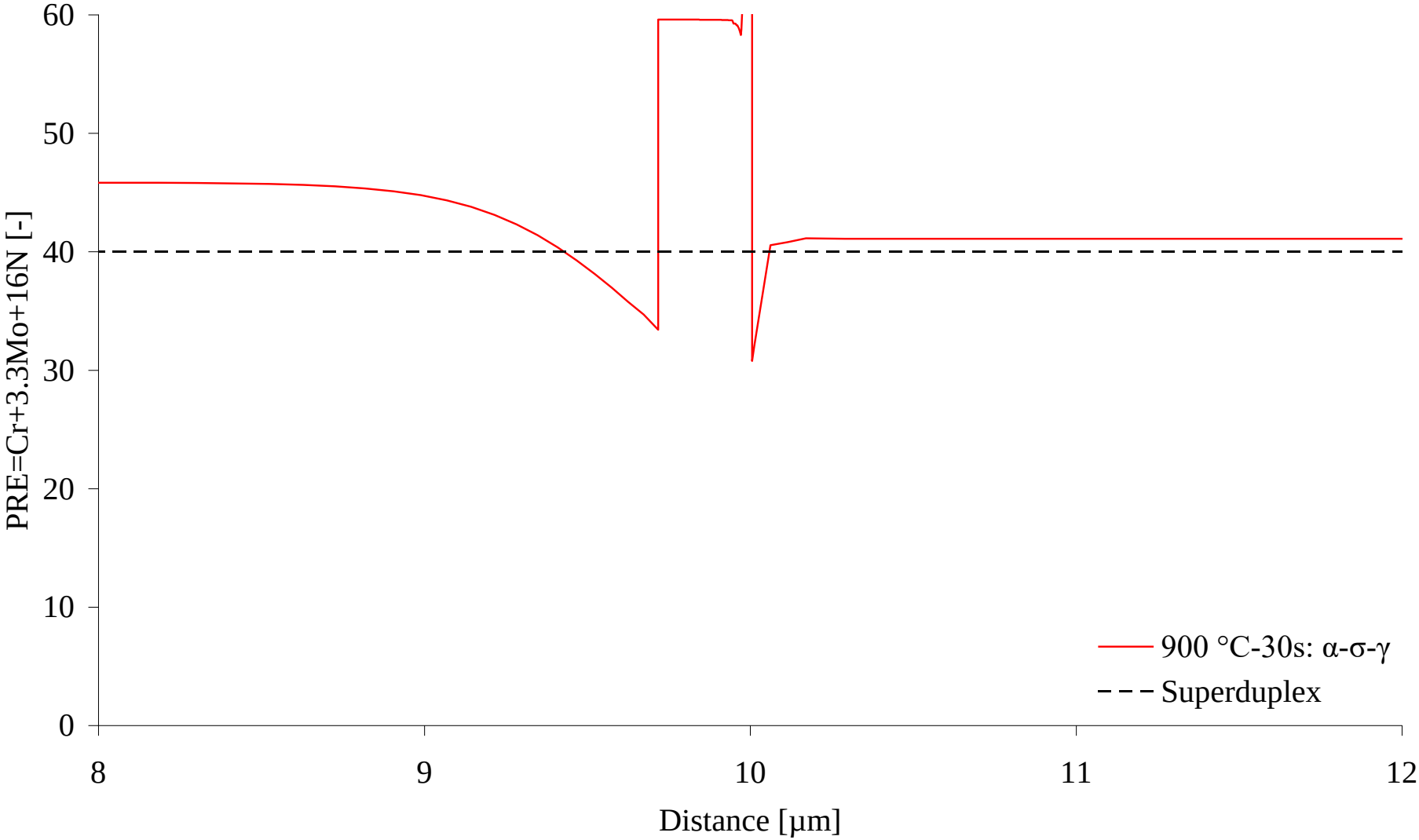

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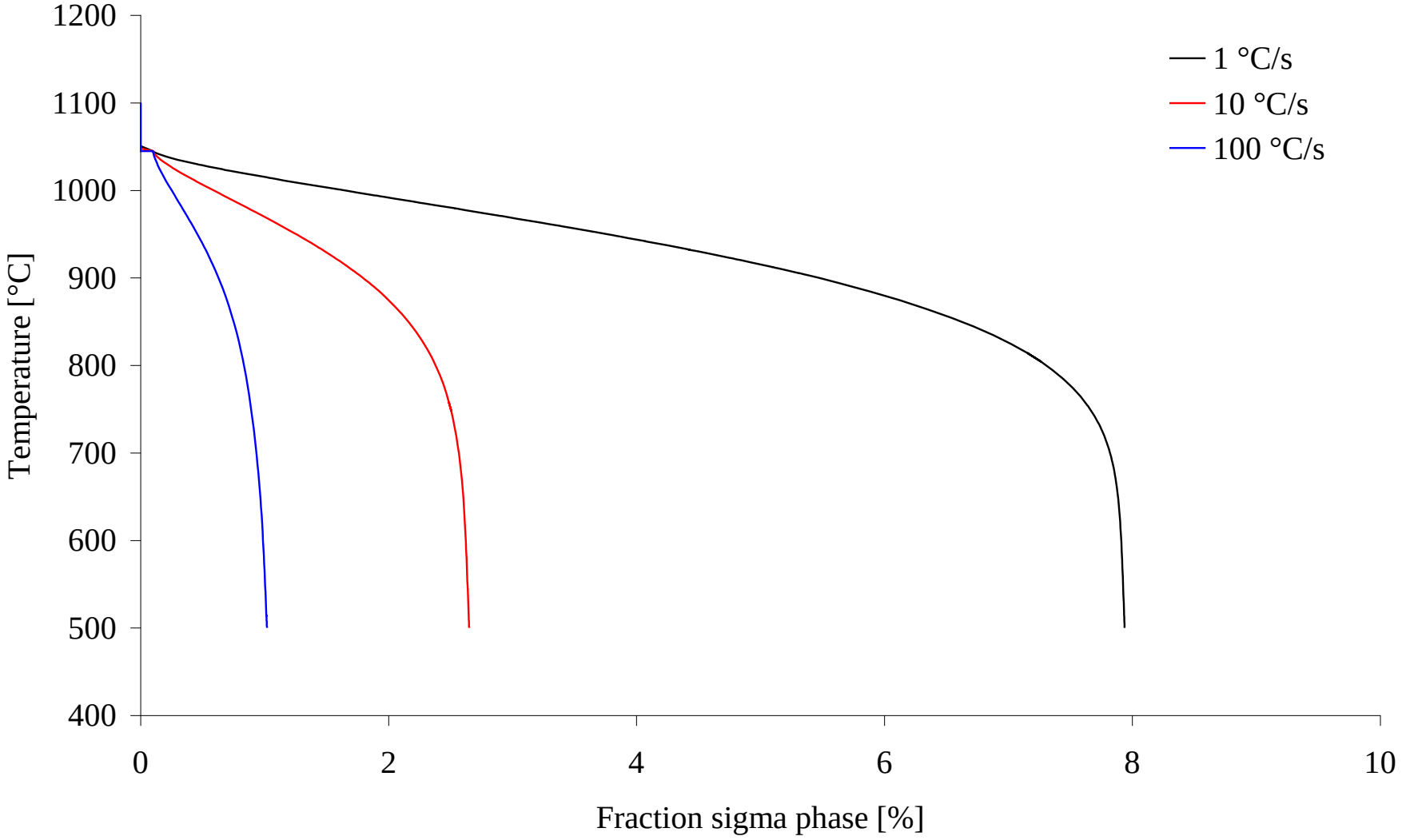

SDN: Continuous cooling

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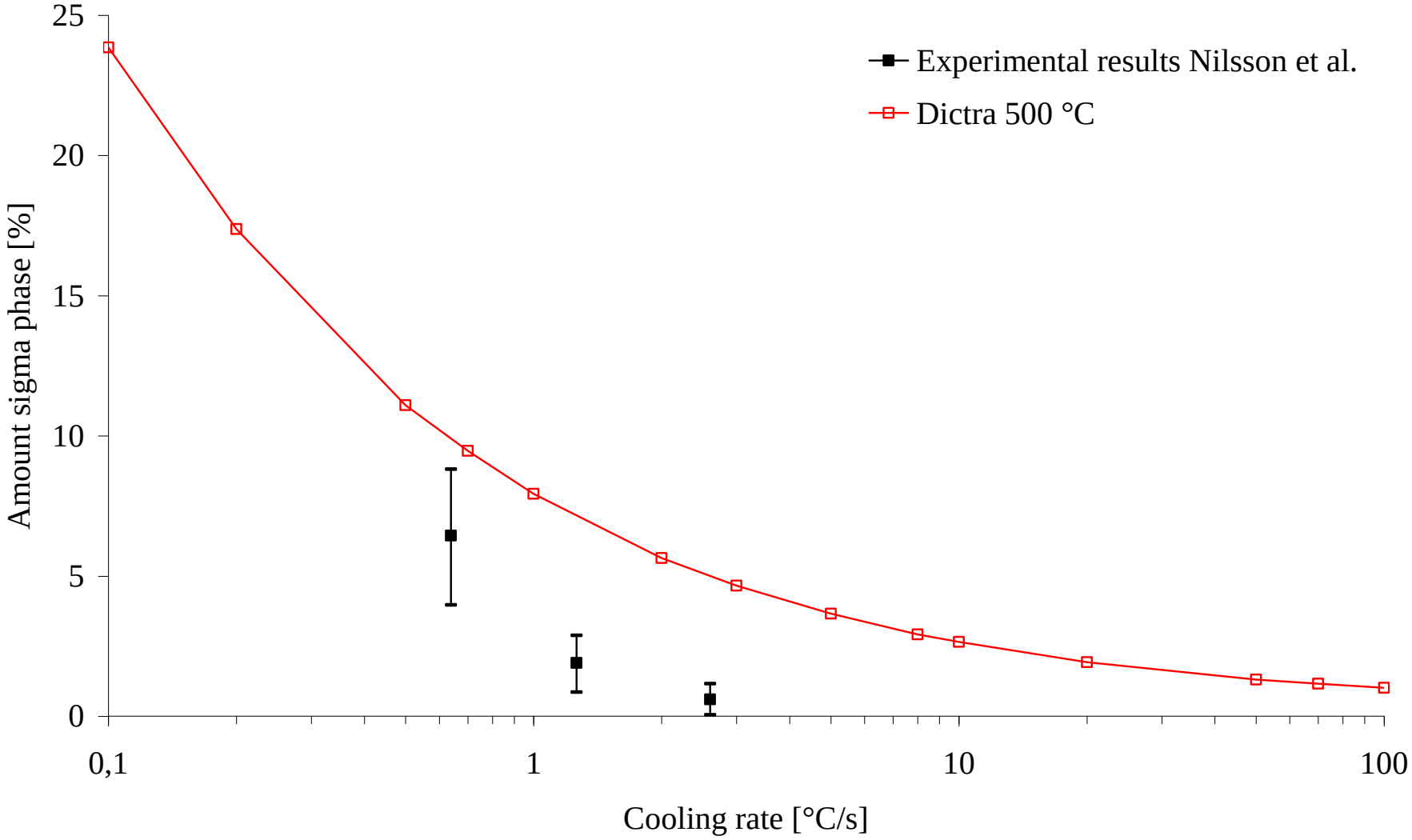

SDN: Continuous cooling

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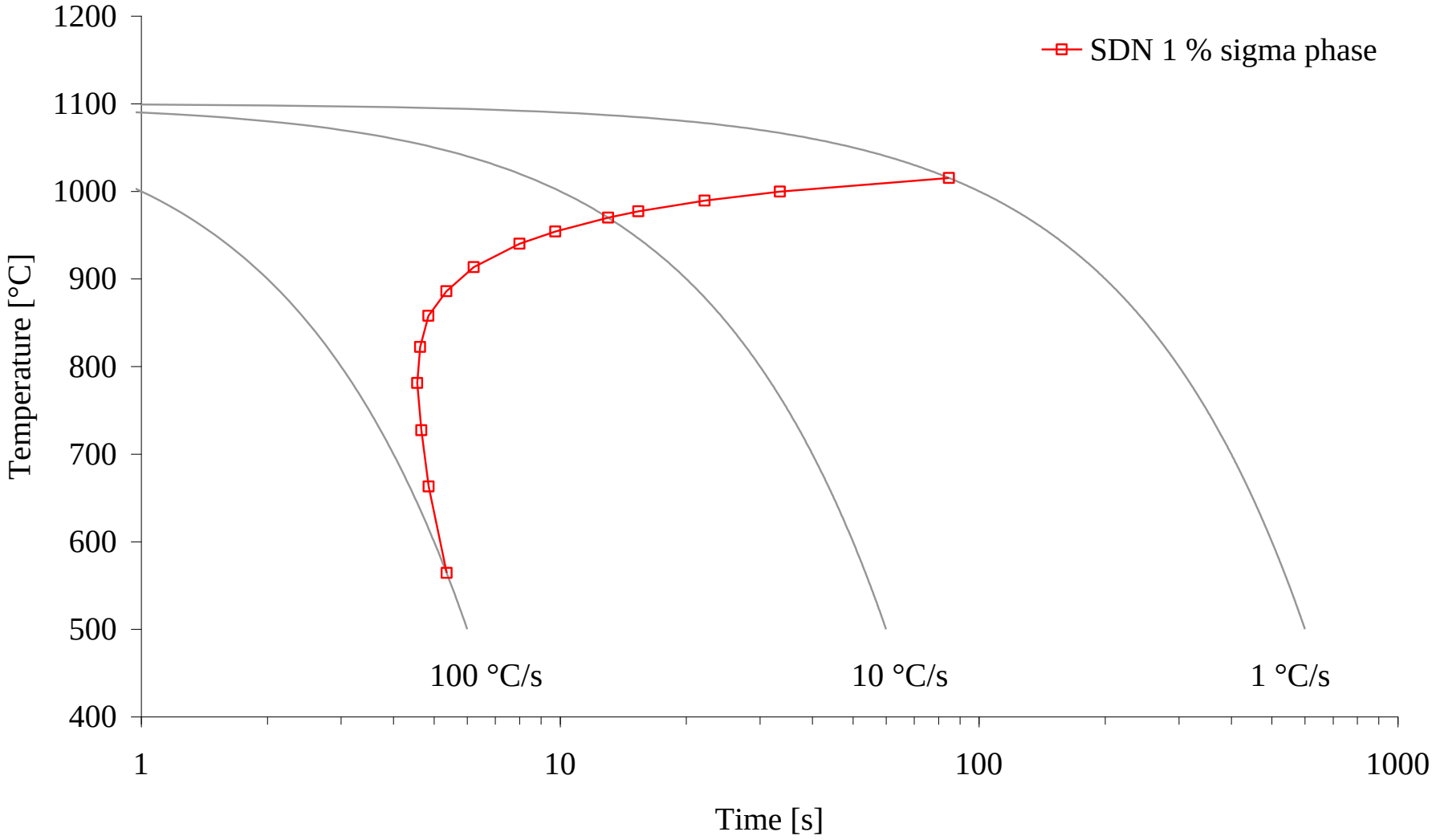

SDN: CCT diagram

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Conclusions:

- DICTRA can be used successfully to reproduce TTT and CCT diagrams.
- Growth of depleted zones adjacent to secondary phases can be studied.
- The influence of alloy composition on precipitation and growth kinetics of intermetallic phases can be derived.
- A good theoretical reproduction of tedious experimental and metallographic work was achieved.
- An extension with nominal compositions gave further insight to the influence of the individual elements W and Cu.

Critical issues :

- Austenite phase was omitted for sake of simplicity.
- Multiple phases was not considered, but the intermetallics one by one.
- Cell size is a **very** critical parameter !
- Nucleation was omitted, by good reason ?

S. Wessman, R. Pettersson: Application of computational thermodynamics to predict growth of intermetallic phases in superduplex stainless steels, Steel Research International 86 (2015).