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EPSRC Centre for Doctoral Training in Innovative Metal Processing (IMPaCT)

Cryogenix
Deep sub-zero processing

The effects of deep cryogenic treatment and austenitising temperature on tempering behaviour of En 31 bearing steel

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1. Introduction

- Retained austenite (RA) in through-hardened roller bearings fabricated from En 31 bearing steel (1C-1.5Cr wt.%) **is undesirable as its thermal and mechanical instability compromises wear performance and dimensional stability**.
- Up to 10 wt.% RA can remain in the microstructure after hardening [1].
- Additional tempering cycles to decompose RA may coarsen cementite and excessively soften the martensite, sacrificing the hardness and strength required to resist repeated contact stresses of 3 GPa [2 & 3].
- **Deep cryogenic treatment (DCT)** is a supplementary treatment step in between hardening and tempering of steel, providing permanent microstructural change not attainable by conventional heat treatment (CHT) processes alone.
- DCT is reported to convert austenite to martensite [4], induce compressive strains in untransformed austenite [5] and enhance carbide precipitation [6] in hardenable steels.
- **DCT therefore represents means of improving dimensional stability beyond the capability of CHT processes, by eliminating or stabilising RA.**
- **This work will aim to establish the correlation between austenitising conditions and the effectiveness of DCT by analysing the stages of tempering.**

2. Methodology

- Process routes A, B, C & D (Figure 1) prior to and after tempering.
- Micro-hardness testing.
- Volume fractions and lattice parameters determined by Rietveld refinement with X-ray diffraction (XRD) data using Materials Analysis Using Diffraction (MAUD) software
- Dilatometry used to detect phase transformations during tempering.
- Subsequent kinetic analysis performed using the Kissinger method with multiple heating rates to determine activation energies of the stages of tempering.
- Stage I: pre-precipitation processes <373 K, Stage II: precipitation of transition carbides 353-473 K, Stage III: decomposition of RA 513-593 and Stage IV: precipitation of Fe_3C 533-750 K.

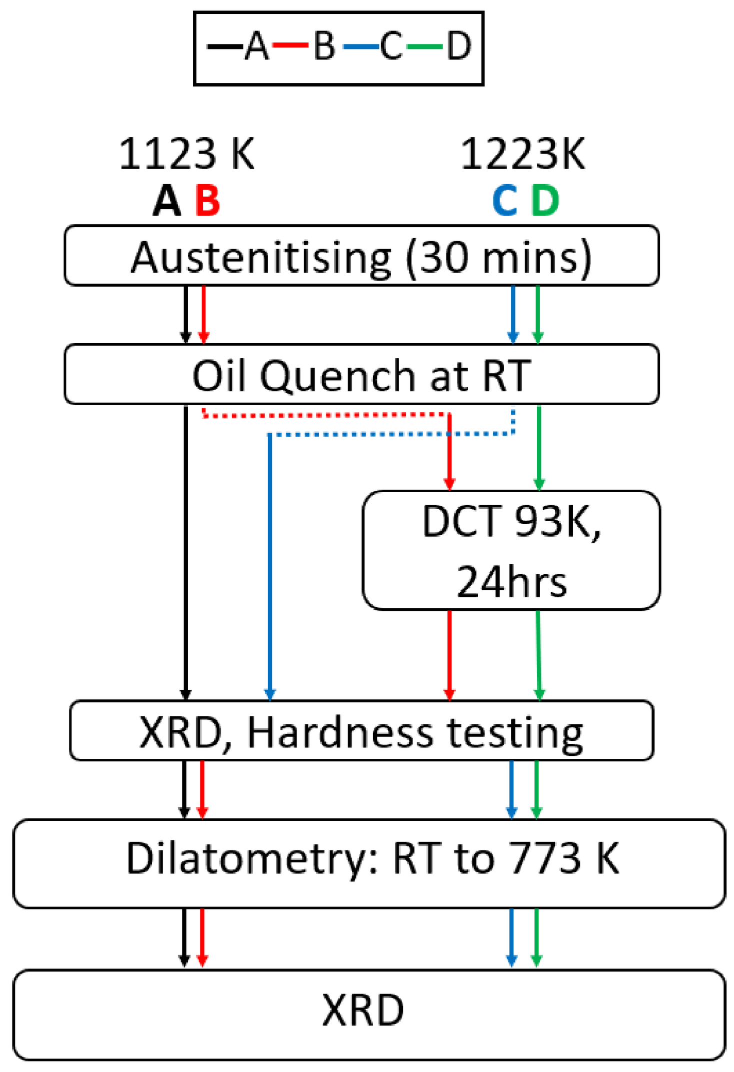

Figure 1: The four microstructural processing routes and characterisation performed.

3. Results

Pre-tempering

Table 1: The volume fractions, lattice parameters and carbon contents in austenite of the four processing routes

Process route	Volume fraction (%)			Lattice parameter (Å)			α' (c/a)	C content in γ, (wt.%)
	α'	γ	Fe_3C	α'_a	α'_c	γ		
A	84.885	10.197	4.9180	2.8644	2.8925	3.5861	1.0098	0.6346
B	87.558	7.4355	5.0065	2.8632	2.8909	3.5902	1.0096	0.7267
C	67.675	32.325	-	2.8626	2.8918	3.5968	1.0102	0.8703
D	73.404	26.596	-	2.8620	2.8892	3.5993	1.0095	0.9263

Table 2: The Micro-hardness results for process routes A, B, C and D.

Process route	Mean HV_{01}	Coefficient of variation (%)	SD
A	804	2.73	21.9
B	818	3.24	26.5
C	722	3.90	28.2
D	807	4.65	37.5

Phase transformations during Tempering

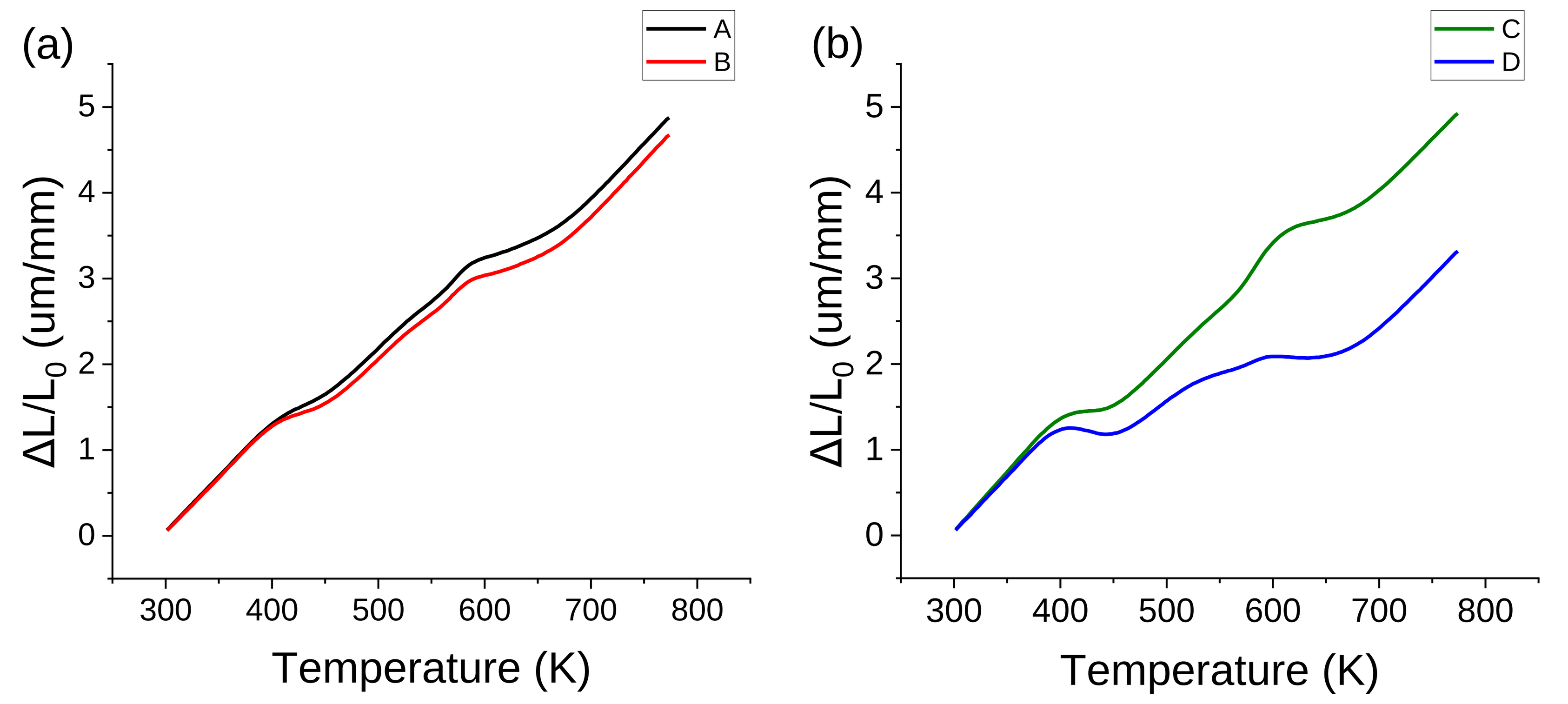

Figure 2: (a) dilatational strain ($\Delta L/L_0$) on tempering for samples A and B, (b) for process routes C and D.

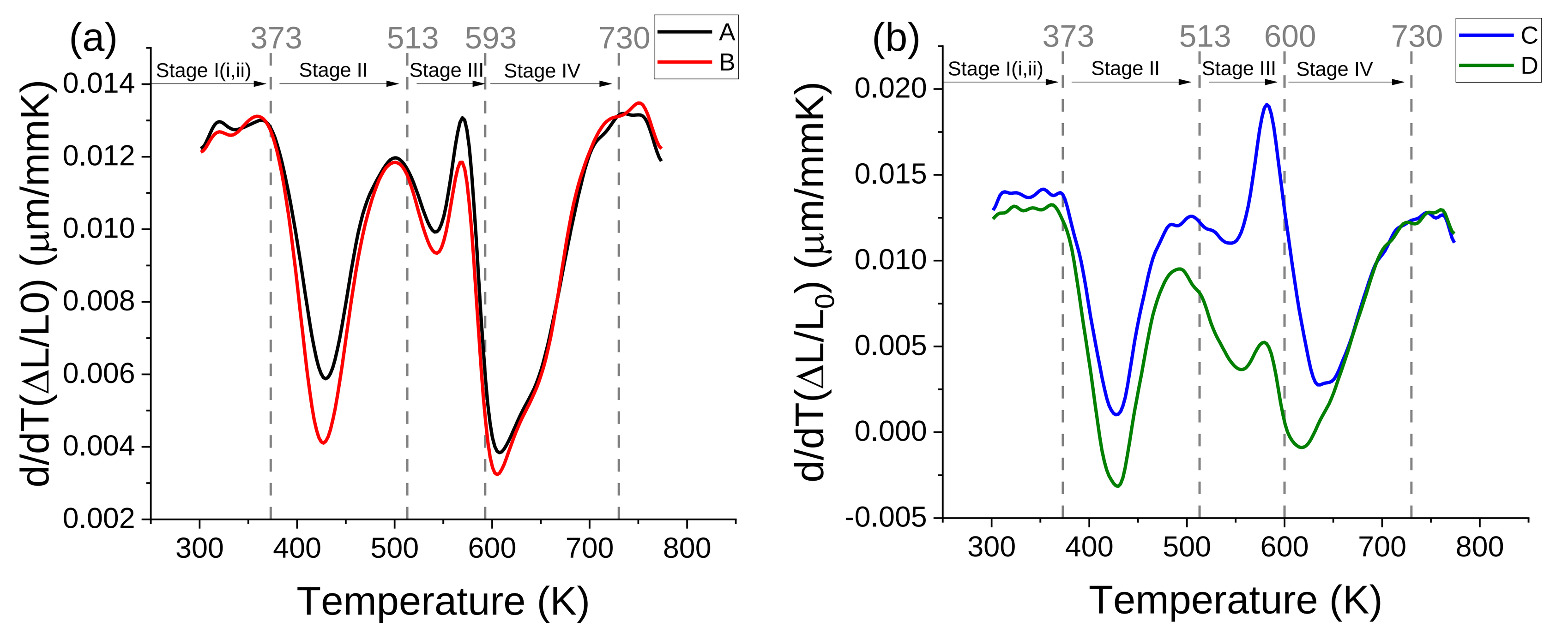

Figure 3: The derivative of the dilatational strain d/dT($\Delta L/L_0$) from Figure 2 shows the stages of tempering. Peak maxima's used as the temperatures of inflection for the Kissinger analyses of each stage.

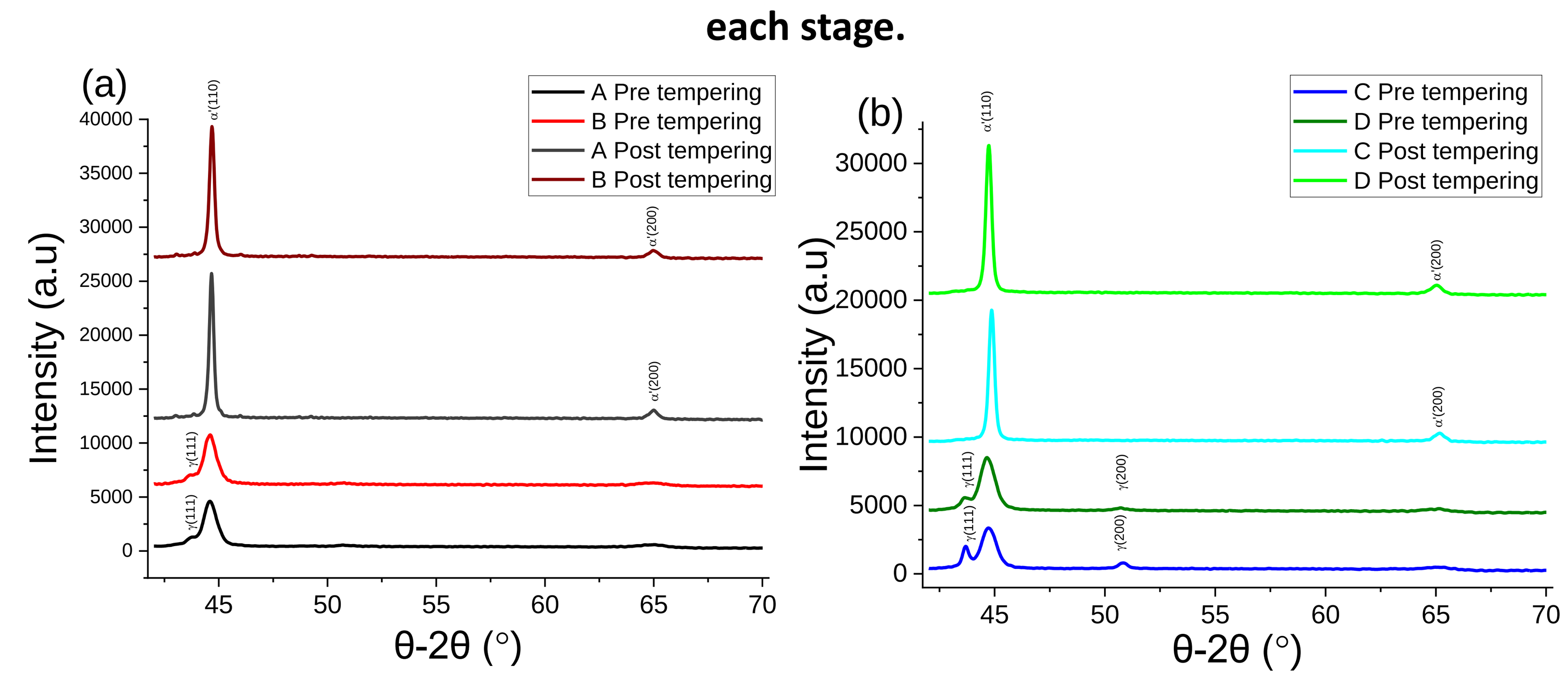

Figure 4: XRD patterns of (a) A vs B and (b) C vs D. All RA in all four processing routes is decomposed beyond the detection limit of the XRD.

Table 3: Activation energies E_a determined by a Kissinger analysis of the stages of tempering.

Process route	Activation Energy, E_a (kJ mol^{-1})		
	Stage II	Stage III	Stage IV
A	112	145	134
B	113	130	153
C	134	146	199
D	136	124	142

4. Conclusions

- DCT reduces the activation energy required for austenite decomposition for all austenitising temperatures.
- DCT reduces austenitic volume fraction, although carbon content in austenite marginally increases thermal stability and resistance to transformation.
- DCT produces an enhanced transition carbide precipitation and Fe_3C precipitation in high austenitised samples, no significant changes in lower austenitised samples.
- DCT increases hardness in higher austenitised samples, a result of the austenite to martensite transformation and the increased carbon in austenite.

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