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Effect of retained austenite and high temperature Laves phase on the work hardening of an experimental maraging steel

S.W. Ooi [a,]*, P. Hill [b], M. Rawson [b], H.K.D.H. Bhadeshia [a]

[a] Department of Materials Science and Metallurgy, University of Cambridge, Cambridge, UK
[b] Rolls-Royce plc, Derby, UK

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ABSTRACT

Maraging steels including the experimental alloy studied here show atypical stress–strain behaviour during tensile testing. In particular, there is a gradual decrease in the ability of the sample to support a stress following a small fraction of the total plastic strain to failure. It is demonstrated here that this phenomenon is not associated with the early onset of a necking instability, and that a large amount of the plastic strain beyond the peak stress is uniform. Investigations of microstructure and retained austenite content reveal that the intrinsic microstructure of maraging steels has a poor ability to work harden. The work hardening capacity can, as expected, be improved by introducing retained austenite, but there is an associated reduction in strength. Experiments have been designed to control the retained austenite content in such a way that clear comparisons can be made and conclusions reached on both the role of the austenite and of Laves phase generated at different temperatures.

1. Introduction

Maraging steels typically have a very low carbon concentration so that after austenitisation, quenching results in a microstructure which is predominantly soft-martensite, which is then hardened by the precipitation of intermetallic compounds. Some austenite may be retained on quenching, but enriched austenite can grow by reversion if the hardening temperature is too high. Maraging steels are well-known for their outstanding combination of strength, fracture toughness and machinability in the solution annealed condition, minimum distortion during subsequent ageing; depending on the chemical composition, the steel can also be stainless. As a consequence, maraging steels have many applications, for example in the manufacture of crankshafts, gears, tools, rocket and missile casings [1–5].

Many earlier studies of maraging steels have focused on the precipitation behaviour and the effect of austenite reversion during the maraging heat treatment [6–13]; investigations of the effect of the solution treatment condition have focused on maintaining a small austenite grain size [14–17]. The purpose of the present work was to establish in a newly designed high-chromium and low-nickel maraging steel, the effect of retained austenite and high temperature Laves phase formation on the work hardening ability. This is because the stress–strain curve exhibits untypical behaviour where the deformation following the peak stress continues over a large range of plastic strain at gently decreasing stress, prior to final failure. This characteristic is irrespective of whether the stress and strain are plotted as true or engineering values. The understanding of this behaviour is limited [18–22].

2. Experimental procedure

The alloy was produced in a vacuum-induction furnace and the composition is shown in Table 1, and cast into a 150 mm × 150 mm × 410 mm ingot. After removal of the shrinkage cavity, the remaining material was heated to 1200 °C and then forged into a 50 mm × 50 mm cross-section blank. The blank was homogenised at 1200 °C for 48 h, furnace cooled, reheated to 1200 °C before being hot rolled to 19 mm diameter rod. The martensite-start temperature (M_S) was measured using a precision dilatometer (Thermecmaster-Z) and the data interpreted using the offset method described elsewhere [23]. The measured martensite-start temperature is also shown in Table 1.

Bars about 80 mm long were cut from the hot-rolled samples. Solution heat–treatments were performed in a box furnace with the temperature range of 725–900 °C for 1–30 h, followed by air

Table 1
The chemical composition of the experimental maraging steel (in wt%). The M_S temperature was measured at a cooling rate of 30 °C s^{-1}.

C	N	Ni	Cr	Co	Mo	W	Ti	Al	M_S (°C)
0.013	0.013	10.02	7.93	8.14	2.79	2.29	0.49	0.2	97 ± 12

* Corresponding author. Tel.: +44 1223334495; fax: +44 1223334567.
E-mail address: swo23@cam.ac.uk (S.W. Ooi).

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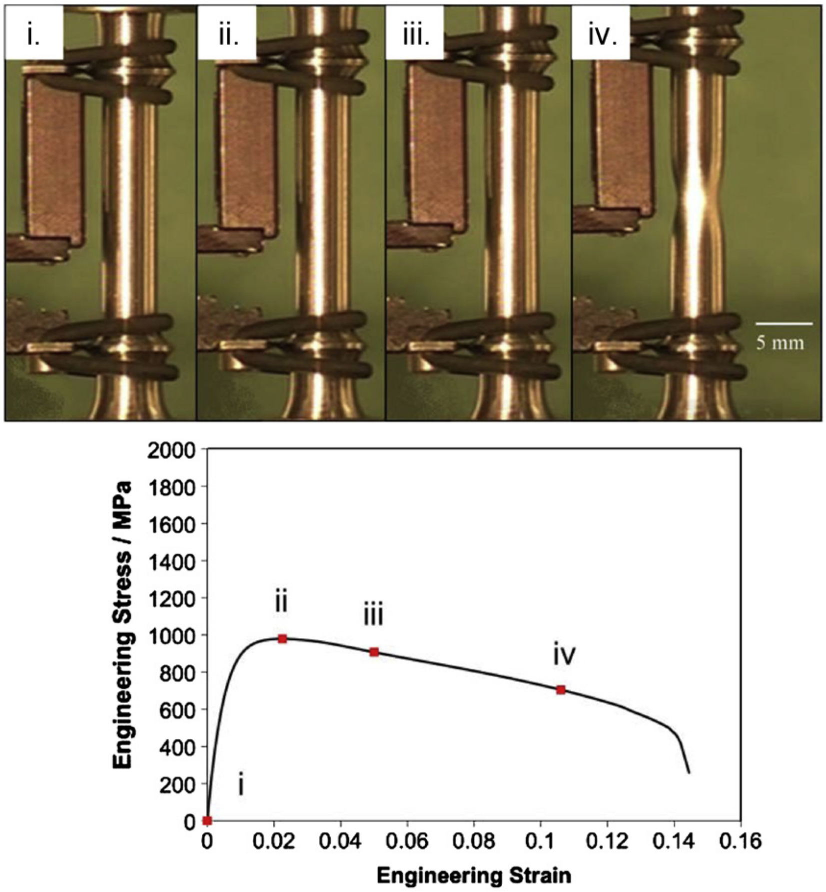

Fig. 1. Evolution of tensile specimen shape and corresponding engineering stress–strain curve during tensile testing for solution treated specimen. The complete heat-treatment given to the sample prior to testing is 900 °C for 1 h, −196 °C for 2 h.

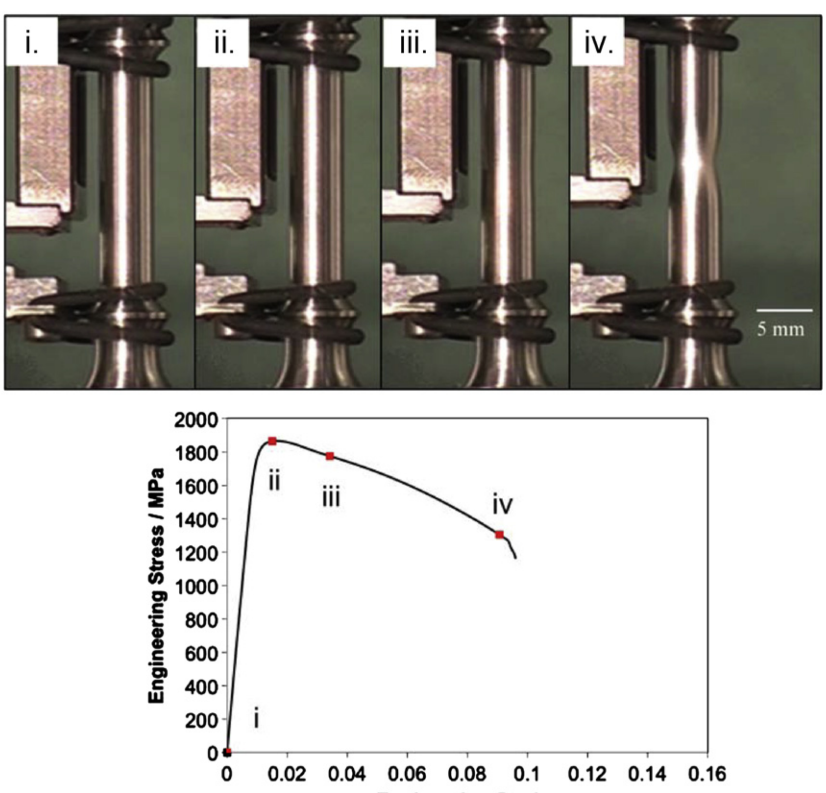

Fig. 2. Evolution of tensile specimen shape and corresponding engineering stress–strain curve during tensile testing for aged specimen. The complete heat-treatment given to the sample prior to testing is 900 °C for 1 h, −196 °C for 2 h and 450 °C for 25 h.