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Modelling mechanical property recovery of a linepipe steel in annealing process

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ABSTRACT

In this paper a set of mechanism-based unified viscoplastic constitutive equations has been used to model the effect of microstructural evolution on mechanical property recovery in the annealing process of a cold formed linepipe steel. Dislocation density and plasticity-induced damage accumulation during deformation, and recovery and recrystallisation of the deformed material during subsequent annealing have been modelled. The effects of annealing time on microstructural evolution also have been investigated. Tensile tests were performed on the low carbon ferritic linepipe steel before and after annealing at 700 °C with different holding times. The experimental results have been used to characterise the unified constitutive equations, using an Evolutionary Programming (EP)-based optimisation method. Using these equations, the stress–strain relationships for the interrupted constant strain rate tensile tests were predicted and close agreement between the computed and experimental results was obtained, for various annealing times and for the materials with different amounts of pre-deformation.

1. Introduction

Linepipes made by the UOE process (Fig. 1) are widely used for oil and gas transportation and are made from hot rolled steel plates (Wen et al., 1999). During the manufacturing process, edge preps are first machined at the two long edges of the plate in order to better accommodate the submerged arc welding (SAW) later in the process. The edge prepped plate is then incrementally fed into a C-press to

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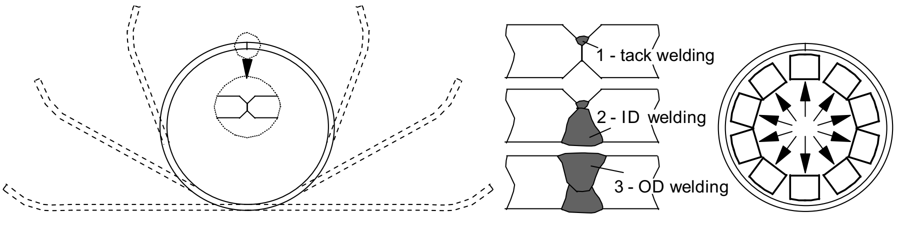
Nomenclature

$\varepsilon_T, \varepsilon_p$	total and plastic strains,
D	total damage,
ω_1, ω_2	damage nucleation and growth variables,
σ	stress,
E	Young's modulus,
a_1, a_2, n_1, n_2, n_3	material constants in damage growth equation,
d_0	material constant for grain size dependence,
d	average grain size,
G_1, G_2, ψ_1, ψ_2	material constants in grain size evolution equation,
X	recrystallisation onset parameter,
X_1	material constants in recrystallisation onset equation,
S	recrystallised volume fraction variable,
$\bar{\rho}, \bar{\rho}_c$	normalised dislocation density, normalised critical dislocation density
H, λ_1	material constants in recrystallisation equation,
k_1, δ_1	material constants in dislocation accumulation equation,
C_r, δ_2	material constants in static dislocation recovery equation,
C_S	material constants in static dislocation recovery by recrystallisation equation,
R	isotropic hardening variable,
B	material constants in isotropic hardening equation,
K	yield stress,
K, n, γ	material constants in plastic strain rate equation,
$\hat{\sigma}$	internal stress,
M, G, b, α	texture of the polycrystalline structure, shear modulus, Burger's vector, material constant,
ρ, l	dislocation density, dislocation mean free path,
K_1, K_2	material constants,
R	static recovery coefficient,
r_0, U_0, K_B, β	material constants in static recovery coefficient equation,
T, t	temperature, time,
ρ_i, ρ_c	initial dislocation density, critical dislocation density,
σ_{surf}, τ, d^*	material constants,
F_R	driving pressure for recrystallisation,
p, q	material constants in Avrami equation,
ε, Z	strain, Zener–Hollomon parameter,
C, a, e, c	material constants,
N, f	material constants in grain size evolution equation,
m, γ_0	material constants in grain growth equation.

have the long edges crimped. After that, the plate is then formed into a U-shaped skelp in a U-press. Following this, the U-skelp is then further deformed in an O-press to form an O-shaped pipe with a



(a) Pipe forming (b) Seam welding (c) Pipe expanding

Fig. 1. Linepipe manufacturing process using the UOE method (Wen et al. 1999).