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Comparative studies on near-threshold fatigue crack propagation behavior of high manganese steels at room and cryogenic temperatures

Dae-Ho Jeong [a], Soon-Gi Lee [b], Jang-Yong Yoo [b], Jong-Sub Lee [b], Sangshik Kim [a,*]

[a] Department of Materials Science and Engineering, RECAPT, Gyeongsang National University, Chinju, Republic of Korea
[b] Technical Research Laboratory, POSCO, Pohang, Republic of Korea

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ABSTRACT

The near-threshold fatigue crack propagation behavior of high manganese steels, including 24Mn4Cr, 22Mn3Cr, 20Mn, 18Mn and 12Mn steels, were examined at 298, 173 and 113 K, and the results were compared to those of widely used cryogenic alloys, including STS304, 9% Ni and 5% Ni steels. The near-threshold FCP behavior of high manganese steels was in general excellent at both room and cryogenic temperatures as compared to the reference cryogenic steels. The near-threshold ΔK values tended to be inversely proportional to the stacking fault energy values of high manganese steels. The fractographic analysis suggested that the SFE mostly affected the slip reversibility of high manganese steels in near-threshold ΔK regime.

1. Introduction

Large research efforts have been conducted on developing high manganese (Mn) steels with an excellent strength–ductility combination at ambient and cryogenic temperatures utilizing transformation-induced plasticity (TRIP) and twining-induced plasticity (TWIP) effects [1–3]. High-Mn steels with Mn content ranging from 15 to 30 wt.% are to be used in a variety of applications requiring high strength–ductility combination at room and cryogenic temperatures. Plastic deformation of high-Mn steel is partially influenced by either TRIP or TWIP effect [4,5,8]. The amount of each effect tends to vary depending on the stacking fault energy (SFE) which is largely determined by chemical composition [6–9], thermo-mechanical treatment [10] and temperature [11]. It has been reported that both TRIP and TWIP effects can occur in the Fe–Mn–C system with an SFE value lower than 18 mJ/m^2, while mechanical twinning takes place for SFE values ranging between 12 and 35 mJ/m^2 [12,13]. Unlike the monotonic loading condition, it has been suggested that no new mechanical twins are formed under fatigue loading [14,15]. The formation of mechanical twins necessitates that the dislocation slip is homogenous with length scale close to the initial grain size [15]. It is however argued that under fatigue loading, the deformation is not homogeneous enough to cause mechanical twinning, rather forming local intense slip bands with strongly localized plasticity [16].

Due to the promising low temperature tensile properties and fracture toughness, high-Mn steels have been developed for cryogenic

Table 1
The chemical compositions of high-Mn steels.

Material	C	Mn	Cr	Ni	Fe
24Mn4Cr	0.45	24	4		Bal.
22Mn3Cr	0.6	22	3		Bal.
20Mn	0.6	20			Bal.
18Mn	0.6	18			Bal.
12Mn		12			Bal.
STS304	0.08	2	18–20	8–10.5	Bal.
9% Ni	0.06	0.65		9	Bal.
5% Ni	0.08	0.6		5	Bal.

Table 2
The tensile properties and ΔKth values of high-Mn steels at 298, 173 and 113 K.

Material	Temperature (K)	Yield strength (MPa)	Tensile strength (MPa)	Tensile elongation (%)	ΔKth (MPa√m)
24Mn4Cr	298	499	982	72	9.0
	173	637	1215	58	14.1
	113	778	1404	56	15.1
22Mn3Cr	298	462	1016	63	5.5
	173	592	1180	44	9.8
	113	592	1175	41	9.6
20Mn	298	526	996	55	8.0
	173	515	1195	59	15.2
18Mn	298	410	1078	68	9.8
12Mn	298	668	969	27	5.1
STS304	298	297	814	47	4.5
9% Ni	298	669	709	25	5.2
5% Ni	298	602	661	25	5.5

* Corresponding author.
E-mail address: sang@gnu.ac.kr (S. Kim).

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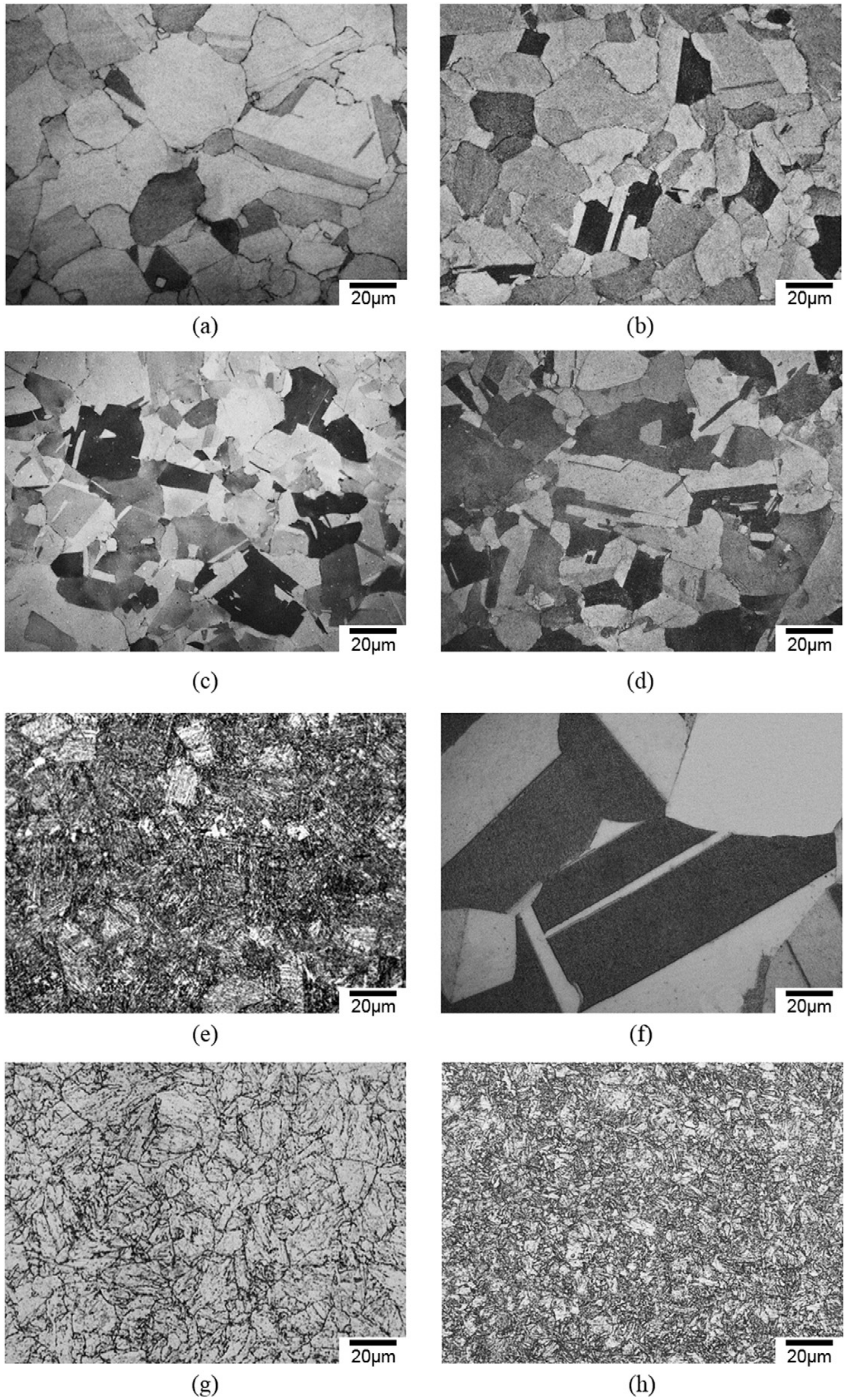

Fig. 1. The optical micrographs of (a) 24Mn4Cr, (b) 22Mn3Cr, (c) 20Mn, (d) 18Mn, (e) 12Mn, (f) STS304, (g) 9% Ni and (h) 5% Ni steels.