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Tensile property and microstructure of Fe-22Mn-0.5C TWIP steel

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A R T I C L E I N F O

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A B S T R A C T

The tensile property and microstructure evolution of Fe-22Mn-0.5C TWIP steel under different annealing conditions was experimentally investigated. The matrix phase of this steel after annealing and tensile test is single austenite. The (111) peak is the most pronounced under as annealed condition, however, its intensity decreases significantly after stretched to fracture where (220) peak becomes the most dominant. The yield strength and tensile strength of Fe-22Mn-0.5C TWIP steel mainly decrease as annealing temperature increases, while the total elongation largely increases. The variation in the product of tensile strength and total elongation against temperature is related to the annealing time. The most obvious change in strength and elongation is located between 750 and 850 °C, due to the grain coarsening in the recrystallized matrix. The grain size and density of annealing twins in Fe-22Mn-0.5C TWIP steel increases with increasing anneal temperature. The recrystallized grains grow obviously as annealing temperature and time increase. The influence of annealing time changing by 15 min on grain growth is not as obvious as temperature changing by 100 °C under the current condition. The tensile strength of Fe-22Mn-0.5C TWIP steel decreases as grain size increases while the total elongation increases. The variation in strength and elongation against the square root of grain size follows Hall-Petch's law well. In order to get a good combination of strength and ductility, the grain size between 10 and 30 μm for TWIP steel is preferentially suggested, within which the product of strength and ductility can be easily adjusted to higher than 65 GPa%. High strength and ductility can be obtained in full-recrystallized Fe-22Mn-0.5C TWIP steel with fine-grained matrix. The high strength TWIP steel with tensile strength above 1030 MPa and total elongation about 60% can be prepared by annealing at 650–750 °C for 15–20 min. The high ductility TWIP steel with tensile strength around 900 MPa and total elongation beyond 70% can be manufactured by annealing at 850–950 °C for 5–10 min.

1. Introduction

Twinning induced plasticity(TWIP) steel has been regarded as one of the best candidates for the lightweight of automobile, attributed to the appreciable combination of high strength, high ductility and high work hardening ability. The application of TWIP steel in car-body components leads to the increase in safety but decrease in both fuel consumption and exhaust emission. Since TWIP steel was commercialized a few years ago, more and more attention has been attracted to the topics on its composition design, property enhancement and deformation mechanism [1–3].

Grassel and Frommeyer introduced a high manganese steel in Fe-Mn-Si-Al system about 20 years ago [4,5]. The tensile strength and elongation under strain rates within $10^{-4}-10^{3}\,s^{-1}$ reach 600–900 MPa and 60–90% respectively. Scott and Allain designed a new kind of TWIP steel in Fe-Mn-C system later [6,7]. The tensile strength is about 1000 MPa and the total elongation is above 50%. It has been widely accepted that the mechanical property of a TWIP steel is strongly dependent on microstructure and grain size, which is closely related to the rolling and annealing. Bracke and Verbeken [8] made a research on microstructure and texture evolution during cold rolling and annealing of Fe-Mn-C TWIP steel. In that study, full recrystallization was observed after annealing at 600 °C for 120 s in the sample with 50% reduction. Kang and Jung [9] focused on the effect of annealing temperature on microstructure and mechanical properties of Fe-18Mn-0.6C-1.5Al TWIP steel. They found that the recrystallization after 60% cold reduction started from 600 °C and finished at 700 °C with a holding time of 10 min. The coarsening temperature of recrystallized grains was 840 °C. The excellent strength and ductility was obtained with grain diameter between 2 and 5 μm after heat-treated at 700–800 °C. Schinhammer and Pecnik [10] investigated the recrystallization behavior, microstructure evolution and mechanical properties of biodegradable Fe-21Mn-0.7C(−1Pd) TWIP steel. It was found that the matrix with total reduction higher than 56% recrystallized partially after annealing for 10 min at 700 °C, while completely at 950 °C. The recrystallized

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Table 1
Chemical composition of investigated steels, wt%.

C	Si	Mn	P	S	Al	T.O	T.N	SFE, mJ mol^{-1}
0.52	0.17	22.18	0.005	0.005	< 0.005	0.0017	0.0050	23.0

grains coarsened significantly when annealed at 1150 °C. The sample soaked at 900 for 10 min exhibited the most favorable mechanical property with tensile strengths between 970 and 980 MPa and total elongation about 60%. Tian and Bai [11] studied the variation in grain size and tensile behavior of Fe-22Mn-0.6C TWIP steel by a multistep rolling-annealing operation. It was noticed that recrystallization after 92% cold reduction was partially completed after annealing at 550 °C for 1 min and 2 min, while fully completed for 4 min. The tensile strength of the fully-recrystallized sample reaches 1247 MPa and uniform elongation approaches 50% with mean a grain size about 0.55 µm. Yuan and Chen [12] analyzed the mechanical properties of Fe-25Mn-3Cr-3Al-0.3C TWIP steel at different annealing temperatures. They found that as the annealing temperature increased from 700 °C to 1000 °C for a constant annealing time about 20 min, the grain size increased from 2.2 µm to 28.7 µm, and the ultimate tensile strengths decreased from 725 MPa to 523 MPa while the elongation increased from 33.2% to 54.2%. In addition, the grain coarsening temperature of this sample was observed to be 900 °C. Yanushkevich and Belyakov [13] investigated the recrystallization behavior of Fe-17Mn-1.5Al-0.3C TWIP steel under the conditions of different cold reduction and annealing temperatures. It was revealed that the cold rolled TWIP steel started to recrystallize at 600 °C with a holding time of 30 min. High reduction during cold rolling results in small recrystallized grains under the same annealing condition. The partially recrystallized sample is with a lower product of strength and elongation than the fully recrystallized. Recently, a new method to increase the yield strength of TWIP steel has been introduced by Haase and Ingendahl [14]. They observed that the matrix of Fe-23Mn-1.5Al-0.3C TWIP steel with 30% cold reduction recovered after annealing at 630 °C for 10 min, and recrystallized after annealing at 700 °C for 15 min. The recovered sample is with a yield strength nearly twice higher than the recrystallized one. In our previous research [15–22], the solidification microstructure, hot ductility, tensile property and strengthening mechanism of Fe-Mn-C TWIP steels was investigated, and the effect of alloying element on mechanical performance and work hardening was also interpreted. Although amounts of achievements have been obtained in the field of high Mn steels in the last decade, the microstructure evolution, grain growth and mechanical property of Fe-Mn-C TWIP steel during annealing has not been elaborated clearly. As mentioned above [10–14], the variation of tensile strength and elongation against annealing parameters is largely scattered in different studies even under similar conditions, and the recrystallization and grain coarsening temperature of Fe-Mn-C TWIP steels is also not very clear. The conclusion on how to prepare a TWIP steel with tailored tensile property has been rarely proposed.

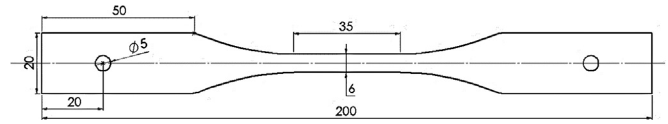

Fig. 2. Sketch of tensile sample for TWIP steel sheet, Unit: mm.

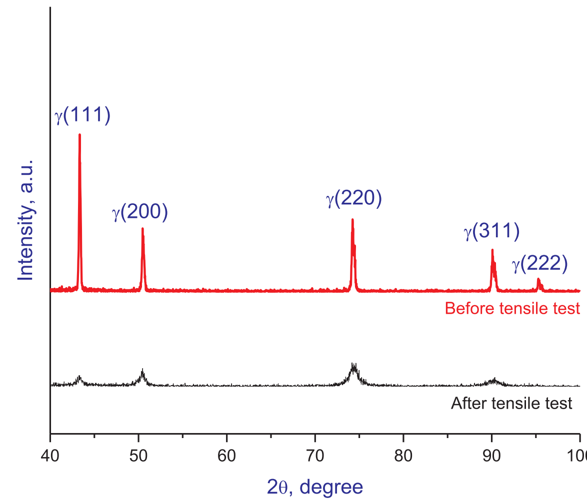

Fig. 3. XRD results of Fe-22Mn-0.5C TWIP steel sample.

Table 2
Tensile properties of Fe-22Mn-0.5C TWIP steel.

Annealing		$R_{P0.2}$, MPa	R_m, MPa	A_t,%	$R_m \cdot A_t$, GPa%
650 °C	5 min	401.93	988.48	58.28	57.61
	10 min	419.88	1043.91	65.41	68.28
	15 min	402.83	1033.82	67.57	69.86
	20 min	402.67	1050.44	65.02	68.30
750 °C	5 min	413.56	1036.57	58.15	60.28
	10 min	392.50	1007.20	60.81	61.25
	15 min	403.78	1037.35	63.50	65.87
	20 min	397.16	1033.91	69.70	72.06
850 °C	5 min	303.19	907.54	75.06	68.12
	10 min	287.63	900.50	75.52	68.00
	15 min	292.64	911.58	65.13	59.37
	20 min	324.23	905.47	66.17	59.91
950 °C	5 min	310.41	953.69	69.05	65.85
	10 min	285.80	897.03	74.04	66.42
	15 min	342.68	904.35	63.79	57.69
	20 min	289.31	896.94	74.13	66.49

The present work is aimed to investigate the effect of annealing temperature and time on the matrix microstructure and tensile behavior of Fe-Mn-C TWIP steel, and reveal the relationship between matrix grain size and mechanical performance. Finally, two annealing routes based on grain control strategy for the tailored tensile property and good combination of strength and ductility of Fe-22Mn-0.5C TWIP steel have been experimentally developed.

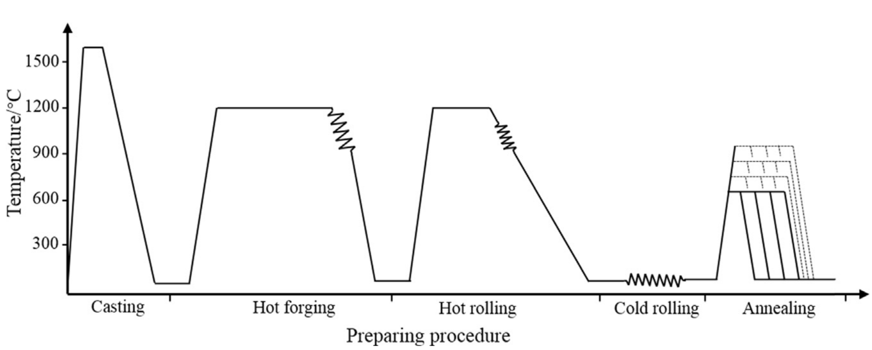

Fig. 1. Preparing procedure of TWIP steel sample.