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Effect of Bearing Mode on Martensite Phase Transformation and Mechanical Property of Constructional Stainless Steel Material

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ABSTRACT: This paper studies martensite phase transformation law and mechanical property change of constructional austenitic stainless steel at different temperature ranges and different bearing modes. The results show that if drop-down loading bearing is adopted for experiment, unloading can promote austenite deformation, which causes martensite phase transformation, nucleation growth and enhanced strain hardening of material, delaying material fracture and necking. In different temperature ranges, influence of different bearing modes on mechanical property of the specimen varies.

KEYWORDS: Austenitic Stainless Steel; Bearing Mode; Martensite; Drop-Down Loading; Phase Transformation Law.

INTRODUCTION

Engineering materials of austenitic stainless steel widely used in construction will undergo martensite phase transformation when its temperature reaches a certain range, and thus can improve toughness and strength of materials [1-2]. Deformation at room temperature occurs in temperature range of TRIP effect, so austenitic stainless steel exhibit good molding capability in practical engineering applications [3], therefore widely used in cold drawing / rolling, hydroforming, and other fields. This paper conducts tensile test of austenitic stainless steel material specimens at different temperature ranges and with two bearing modes of monotonic and drop-down loading, studies specimen mechanical property change rule and martensite phase transformation under different corresponding conditions, and elaborates deeply influence mechanism of different bearing modes on mechanical property of austenitic stainless steel.

EXPERIMENTAL METHOD

Stainless steel chosen in the experiment is AISI 304, with its chemical composition shown in Table 1. MTS5105 type universal testing machine is chosen as tensile test equipment. Normal experimental temperature is controlled at about 20^0C, with high temperature at 200 and 350^0C, low temperature at -25, -50 and -80 ^{0}C. Two modes of monotonic and drop-down loading are applied for tensile test bearing at each temperature segment. Drop-down loading mode can be controlled by stress, with strain recorded by extensometer. Number of loading and unloading can be set according to tensile strength of materials under experimental conditions, while strain rate can be adjusted.

Table 1. The chemical composition of AISI 304 stainless steel materials.

Chemical composition	C	Cr	Mn	Ni	Si	P	S	N	Fe
Mass fraction/ %	0.05	18	1.12	8.07	0.05	0.02	0.01	0.043	Margin

Perform in-situ observation experiment with D8 advance X-ray diffraction (XRD), with ray source as CuK_α X at a width of about 5mm, always intersecting at maximum deformation zone of materials. Operating current and voltage are 300mA and 40kV, maximum power output is18kW, thickness of sample material is 0.3mm. Microstructure of

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stainless steel sample material at different temperature ranges can be observed with Tecnal G^2 20 transmission electron microscopy.

TEST RESULTS AND ANALYSIS

Test Results

At room temperature, conduct uniaxial tensile test of two bearing modes at different strain rates, with main mechanical parameters shown in Table 2. Based on observation of Table 2, strength of monotonic bearing specimen increases significantly with strain rate decrease, but elongation magnitude increase is not obvious; strength of drop-down loading specimen and specimen elongation increase significantly with strain rate decrease. When strain rate is at $1.0x10^{-2}$ s^{-1}, there is almost no big difference in the two bearing modes. When strain rate reduces to a certain value, compared with monotonic bearing tensile, drop-down loading can significantly enhance strength and elongation rate of stainless steel materials and mechanical property of materials becomes better.

Table 2. The mechanical properties at room temperature under the condition of uniaxial tensile test.

Bearing mode	ε,10^{-3} s^{-1}	σ_s, Mpa	σ_b, Mpa	δ
Monotonic bearing	1.0	271	652	0.71
	1.3	276	652	0.72
	3.3	278	644	0.71
	10.0	261	634	0.68
Drop-down loading	1.0	271	712	0.89
	1.3	257	674	0.87
	3.3	272	654	0.85
	10.0	263	636	0.71

Under conditions of high temperature 200^0C and 350 ^{0}C, engineering stress- strain curve obtained by tensile specimen corresponding to the two bearing modes is shown in Figure 1. Compared with tensile results at room temperature, mechanical property of stainless steel specimen shows a significant downward trend. Limiting stress corresponding to 200^0C and 350 ^{0}C is smaller than 460 MPa, dependent variable of specimen fracture is only 0.5, curves obtained by the two bearing modes are basically identical, and there is no significant difference in mechanical property of specimen.

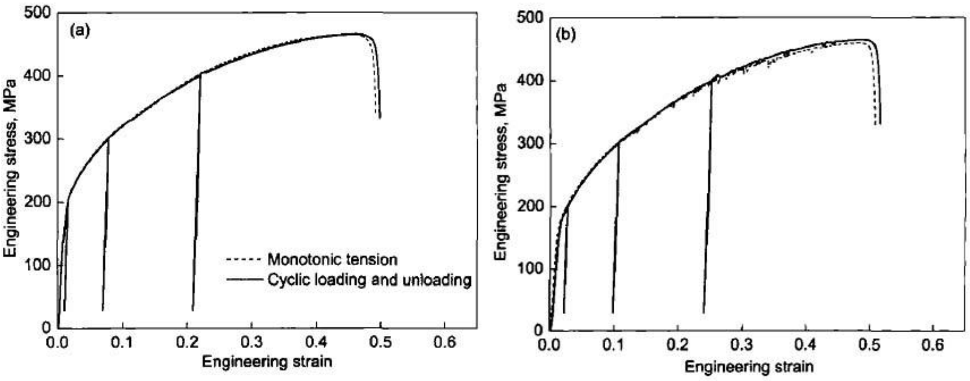


Figure 1. Engineering stress-strain curve is obtained by Unidirectional tensile test under high temperature (a) 200 ^{0}C; (b) 350 ^{0}C.

Low temperature tensile test coincides with bearing and loading and unloading form at room temperature and high temperature conditions, all applying monotonic and drop-down loading for comparison of material properties [4]. At low temperature, engineering stress- strain curve obtained by tensile specimen with the two bearing modes is shown in Figure 2. At lower temperature segment, curve obtained by stainless steel specimen tensile coincides with literature [5] findings. Stainless steel specimen strength corresponding to the two bearing modes increases significantly with temperature decrease, but elongation rate of specimen decreases slightly. When temperature drops to -80^0C, flow stress of stainless steel specimen under monotonic loading gradually lowers than that under drop-down loading, and corresponding elongation rate of stainless steel specimen gradually converges.

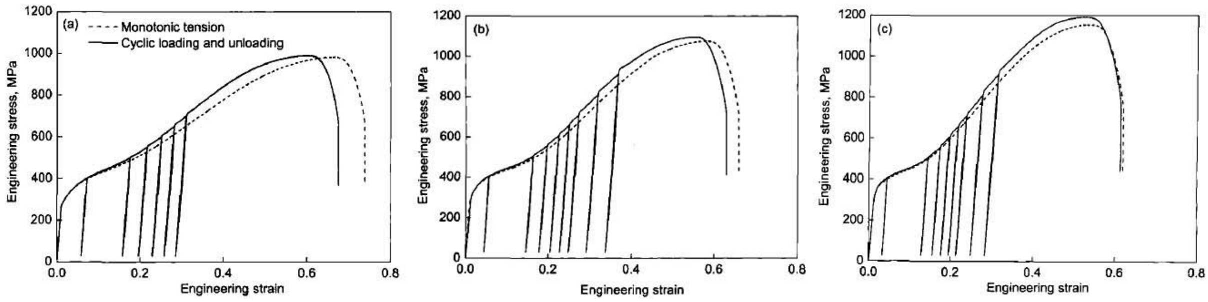


Figure 2. Engineering stress-strain curve is obtained by Unidirectional tensile test under low temperature.

The results of tensile test under different temperature segments show that: Influence law of the two bearing modes on mechanical property of stainless steel specimen material is obviously affected by strain rate and temperature. By in-situ observation of stainless steel specimen tensile under two bearing modes at room temperature, diffraction peak of specimen at various stages of deformation is obtained. Seen from the results of diffraction peak, austenite single phase is only not deformed in stainless steel specimen, and austenite phase is caused by diffraction peak shift due to internal stress of material induced by deformation.

Bearing Mode Effect on Martensite Phase Transformation

Under drop-down loading bearing tensile, TEM imaging law of necking zone of stainless steel specimen can be observed, as shown in Figure 3. Through observation, austenite parent phase (without phase transformation) and martensite laths (induced by deformation) can be seen. Meanwhile, a lot of dislocation pileup is not observed in surrounding area of the two-phase interface. There are many fluctuating segments on engineering stress- strain curve obtained from tensile specimen, which is accompanied by softening and hardening phenomenon caused by austenite phase transformation. Martensite phase transformation increases with increasing strain, while applied stress repeatedly have sudden, significant decrease. In addition, process of drop-down bearing can further extend deformation time of specimen, decrease temperature rise due to deformation of specimen, which is advantageous for martensite phase transformation.

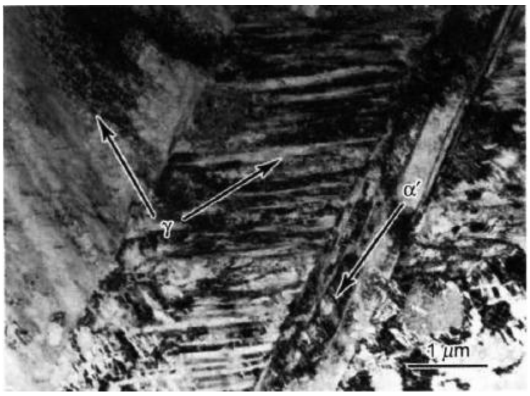
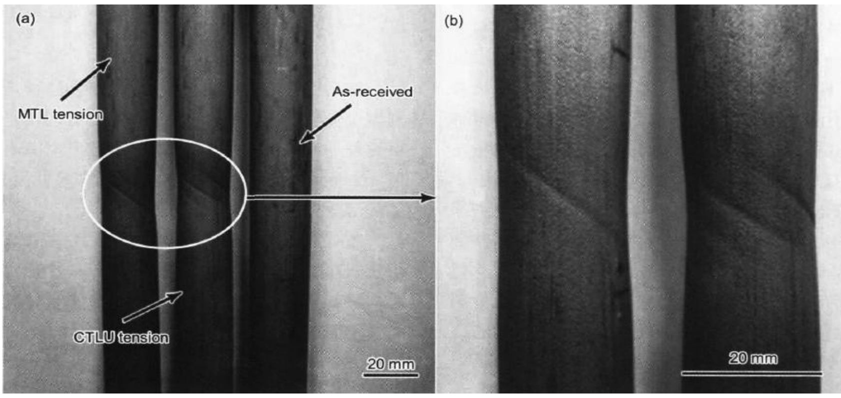


Figure 3. The drop-down loading bearing and necking zone TEM.

Effect of Bearing Mode on Mechanical Property of Stainless Steel Materials

Effects of different bearing modes on mechanical property of stainless steel are mainly affected by martensite to austenite phase transformation induced by material deformation. Meanwhile, phase transformation is also influenced by deformation rate and deformation temperature of materials. In tensile test of specimens under high temperature conditions, the two bearing modes exert no influence on mechanical property of stainless steel materials, which is mainly because temperature inducing martensite phase transformation is lower than deformation temperature of materials, not leading to martensite phase transformation. At room temperature, with continuous decrease in material strain rate, it is increasingly favorable for martensite phase transformation, and bearing mode exerts more obvious effect on mechanical property of stainless steel materials, as shown in Figure 4.



(a) Specimen necking contrast, (b) Local amplification

Figure 4. Different bearing mode specimen necking contrast.

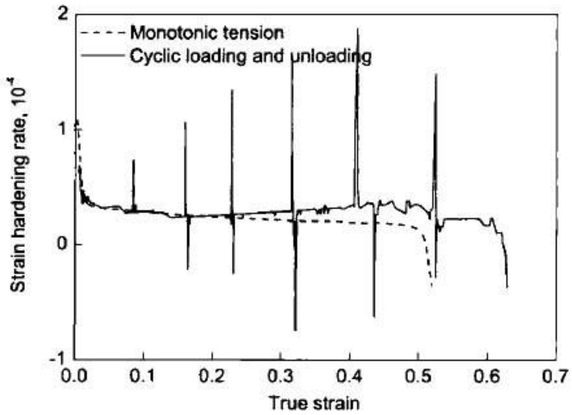


Figure 5. The strain hardening rate and material true strain relationship curve.

At room temperature, when specimen tensile strain rate is $1.0x10^{-3}$ s^{-1}, material rate of strain hardening and variation law between strain materials under the two bearing modes are shown in Figure 5. As can be seen from Figure 5, with the progress of each load-bearing process, stainless steel rate of strain hardening will have phase step, which shows that drop-down loading bearing mode can significantly improve martensite phase transformation possibility of stainless steel materials. The followed material secondary hardening enhances material strength, and delays material fracture and necking, while elongation of stainless steel is improved significantly.

CONCLUSIONS

In-situ tensile observation experiment and tissue analysis can prove that if drop-down loading bearing mode is adopted for experiment, unloading can promote austenite deformation, which triggers martensite phase transformation with nucleation growth, enhances strained material hardening and delays material fracture and necking. Conduct tensile experiment on stainless steel specimen at a high temperature above 200^0C, and the two bearing modes will not exert any impact on mechanical property of specimen. During experiment at low temperature under 0 ^{0}C, different bearing modes exert different effect on mechanical property of specimen. While at room temperature and low strain rate, drop-down loading bearing can significantly increase strength and elongation of specimen.

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