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Effect of Aging on Superelasticity of TiNi Shape Memory Alloy (SMA) with Low Clearance

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Abstract: The effect of aging on superelasticity of TiNi shape memory alloy (SMA) was studied by mechanical property tests. Results indicate that after aging treatment of 300 ℃/60~180 min and aging treatment of 400 ℃/10~30 min, the tensile strengths of TiNi SMA wires are higher than 1000 MPa, and the residual strains are less than 0.31% in loading-unloading tensile tests of 6%. The low clearance TiNi SMA has better mechanical properties and superelasticity after above aging treatments.

Key words: TiNi; ageing treatment; superelasticity

Recently, TiNi SMAs have been widely applied due to the excellent shape memory effect[1-3], superelasticity, as well as good corrosion resistance and biocompatibility[4,5]. For example, the addition of Cr element decreases significantly the phase transition temperature of NiTi alloys[3,6], and leads to nonlinear superelasticity at room temperature (RT). Therefore, TiNi alloys are widely used in glasses manufacture. Flattening, bending and drawing are the common manufacturing processes for glasses frames, which require good cold-workability and superelasticity at room temperature. The effect of aging on superelasticity was studied for Ti-Ni binary SMA wires with high purity and good mechanical properties at RT in the present study.

1 Experiment

The raw materials in the experiments were 0-grade titanium sponge and 1-grade electrolytic nickel, and TiNi ingots were obtained by vacuum melting. The contents of C, O and other impurity elements were reduced through the addition of specific elements, and the chemical composition is shown in Table 1. The ingots were worked into wires by the procedure of forging-rolling-scalping-grinding-drawing, and the samples were prepared from the wires. The annealing treatment of 800 ℃/20 min/WQ was carried out for the samples, and the DSC curves are shown in Fig. 1. The phase transition temperatures of TiNi SMA, such as M_s, M_f, A_s and A_f, are –21.32 ℃, –48.72 ℃, –16.61 ℃ and 4.39 ℃, respectively.

Table 2 shows the processes of heat treatment in the experiments.

For each group samples with different aging treatments, the mechanical tests were carried out at 20 ℃ on electronic tensile testing machine, and the superelasticity was evaluated by comparing the tensile property and residual strain. The length

Table 1 Chemical composition of NiTi alloy (wt%)

Ti	Ni	C	O	H	N	Each	Total
Bal.	54.50~56.50	0.009	0.034	0.004	0.004	<0.1	<0.4

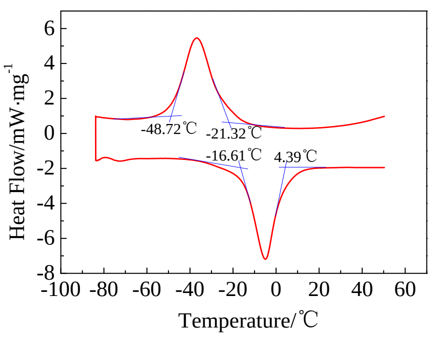

Fig.1 Original DSC curves of TiNi alloy

Table 2 Processes of heat treatment for samples

Annealing Temp./℃	Time/min					
300	5	10	30	60	120	180
400	5	10	30	60	120	180

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of samples and gauge were 220 mm and 100 mm, respectively. The strain rate was 1.0 mm/min.

2 Results and Discussion

2.1 Mechanical properties of original samples

Fig.2 shows tensile and stress-strain curves of original Φ1.8 mm wires. As shown, the tensile curve of original wire is the typical one of straightened wires, and the stress increases linearly without yielding plateau induced by martensitic transition. The tensile strength and elongation is 913 MPa and 42.5%, respectively, and the wires have excellent plasticity. Meanwhile, the stress-strain curve shows residual strain of 1.28%, which demonstrates the strain doesn't fully recover and the superelasticity is not good enough. In order to improve superelasticity, different aging treatments were carried out.

2.2 Effect of aging treatment on mechanical properties

Fig.3 shows the tensile curves of TiNi wires after aging treatments with different time and temperatures. After aging of 300 ℃/5~120 min, the tensile curves are still the typical ones of straightened wires as shown in Fig.3a. However, obvious yield plateaus appear in tensile curves after aging treatments over 180 min, which indicates martensitic transition occurs in the samples during deformation. After aging of 400 ℃/5 min, the tensile curve is still the typical one of straightened wires as shown in Fig.3b. Yield plateaus appear in the curves of samples with aging treatment for 10~30 min, and become more obvious when the aging time is over 60 min. It's indicated that the aging treatments of 300 ℃, 400 ℃/5~120 min improve the plasticity of TiNi wires, and the plasticity increases with the increasing of aging temperature and time.

The tensile strength and area reduction are shown in Fig.4, and the tensile strength increases with aging time. After aging at 300 ℃, the area reduction is over 20%, and reaches the maximum of 46.8% when the aging time is 60 min. Furthermore, aging for 120 min the strength reaches to 1131 MPa. For the aging treatment at 400 ℃, the area reduction is over 35.5%, and reaches the maximum of 42.7% when the aging time is 30 min. However, the area reduction decreases to about 20% with the further extension of aging time. Therefore, the aging treatment for short time improves the tensile properties at RT.

2.3 Effect of aging treatment on superelasticity

After annealing at appropriate temperature for a certain time, Ti_3Ni_4 precipitates are visible in TiNi alloy[7-9]. On the one hand,

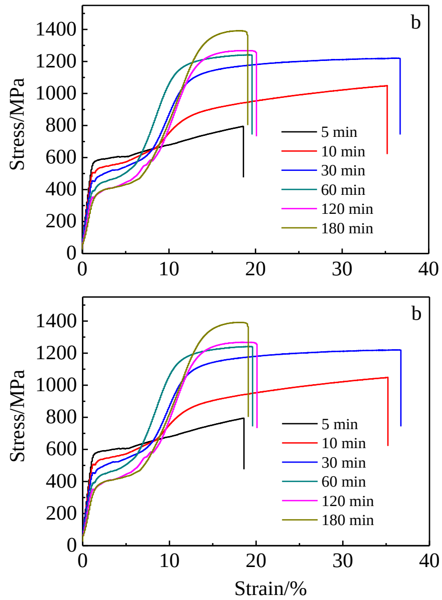

Fig.3 Tensile curves of TiNi wires after aging at 300 ℃ (a) and 400 ℃ (b) for different time

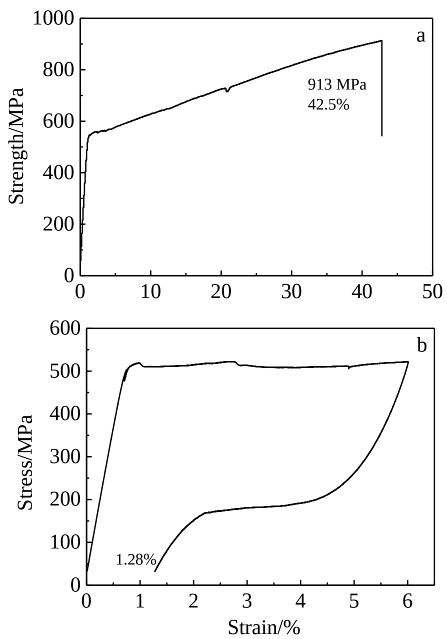

Fig.2 Tensile (a) and stress-strain (b) curves of original wire

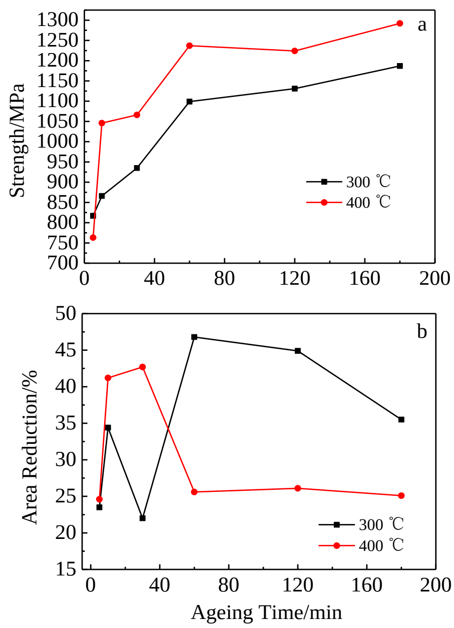

Fig.4 Effect of aging on the tensile strength (a) and area reduction (b)

Ti_3Ni_4 impedes martensitic transition, lowers M_s, and promotes the generation of R phase; On the other hand, Ti_3Ni_4 strengthens the matrix, increases the critical slip stress of TiNi alloy, and makes R phase and martensite exhibit superelasticity, which improves the superelasticity of alloy.

Fig.5 shows the stress-strain cycle curves of TiNi wires after aging treatments with different time and temperatures. As shown in Fig.5a, the residual strain of the wires decreases with the increasing of aging time at 300 ℃. The upper yield plateaus appears after aging for 5~60 min, and the upper and lower yield plateau both appear after aging for 60~180 min. When aging time exceeds 60 min, the loop area decreases, which indicates the decrease of energy consumption in the alloys. When the aging temperature is 400 ℃, all stress-strain cycle curves have yield plateaus. After aging for 30~60 min, the residual strain is less than 0.31%, but increases significantly when aging time reaches to 120~180 min.

Fig.6 shows the residual strain of samples applied loading-unloading tension of 6% after different aging treatments. The residual strain of samples aged at 300 ℃ decreases significantly with aging time, even less than 0.31% when aging time exceeds 60 min. When aging time reaches to 180 min, the strain recovers fully, and the alloys have excellent superelasticity. After aging treatment for 60~180 min, the strengthening of matrix improves the superelasticity. For the samples aged at 400 ℃ for 5~30 min, the residual strain decreases gradually, but increases rapidly to 1.63%~2.95% when aging time exceeds 60 min, which indicates that the aging treatment for over 120 min couldn't strengthen matrix further, but consequently the residual strain increases and the superelasticity decreases significantly.

As shown in Fig.7, after aging at 300 ℃ for 30~180 min,

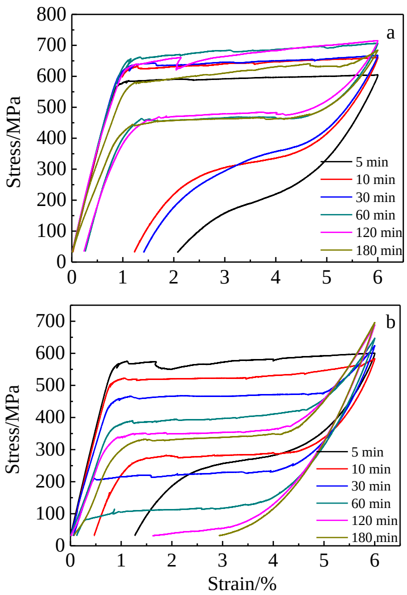

Fig.5 Stress-strain cycle curves after aging at different temperatures: (a) 300 ℃ and (b) 400 ℃

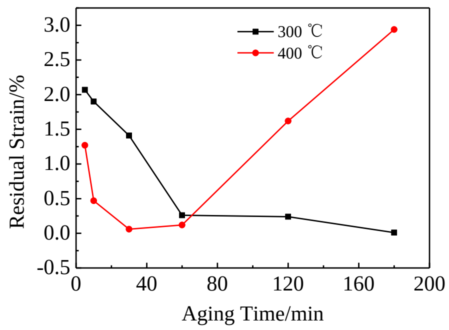

Fig.6 Effect of aging on the residual strain

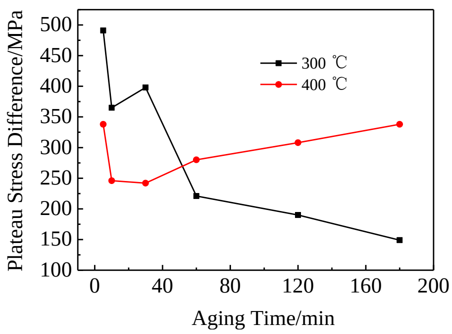

Fig.7 Effect of aging on plateau stress difference

the plateau stress difference decreases gradually. For the samples aged at 400 ℃, the plateau stress difference reaches to the minimum when aging time is 30 min.

3 Conclusions

1) For TiNi SMA, the aging treatments of 300 ℃/60~180 min and 400 ℃/10~30 min both lead to good tensile properties and superelasticity at RT.

2) After the loading-unloading tensile tests of 6%, the residual strain of the samples is less than 0.31%.

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时效处理对低间隙 TiNi 形状记忆合金超弹性的影响

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摘 要：研究了时效处理对低间隙TiNi形状记忆合金超弹性的影响。结果表明，分别经300 ℃/60~180 min及400 ℃/10~30 min时效处理后，TiNi形状记忆合金丝材抗拉强度均大于1000 MPa，经6%应变加载-卸载后，残余应变量均小于0.31%。经以上两种时效处理工艺后，低间隙TiNi形状记忆合金线材均具有良好的力学性能及超弹性。

关键词：TiNi；时效处理；超弹性

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