Development of Hot Drawing Process for Nitinol Tube

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Summary

In recent years, Nitinol, near-equiatomic nickel-titanium alloys, have found growing applications in medical technology and joining technology, due to their special characteristics such as shape memory, superplasticity and biocompatibility. The production of Nitinol tube cost-effectively remains a technical challenge. In this paper, we describe a hot drawing process for Nitinol tube production. A Nitinol tube blank and a metal core are assembled together. The assembly is hot drawn for several passes to a final diameter. The metal core is then plastically stretched to reduce its diameter and removed from the tube. Hot drawing process has been applied to Ni50.7Ti and Ni47Ti44Nb9 alloys. Nitinol tubes of 13.6 mm outer diameter and 1 mm wall thickness have been successfully produced from a tube blank of 20 mm outer diameter and 3.5 mm thickness.

1. Introduction

In the last few decades, it is always difficult to produce NiTi shape memory alloy tube. Thermomechanical processing of NiTi tube is one of areas that attract increasing attentions from researchers all over the world [1-5]. NiTi tube, especially Nitinol tube (near-equiatomic nickel-titanium alloys), has many applications in tube joining, medical implant tube, cardiovascular stents, and various of robotics. There are only few companies in the world that can produce NiTi-based shape memory alloy tubes [4-6]. The production of Nitinol tube cost-effectively remains a technical challenge [6-9]. In this paper, we describe a hot drawing process for Nitinol tube production. A Nitinol tube blank and a metal core are assembled together. The assembly is hot drawn for several passes to a final diameter. The metal core is then plastically stretched to reduce its diameter and removed from the tube. The hot drawing process has been detailed studied and the process parameters have been optimised.

2. Experiments

The alloys used in this study were NiTi (50.7 at.%Ni-Ti) and NiTiNb (Ni47Ti44Nb9). The hot drawing was performed on an assembly of tube blank and metal core. The tube blanket was drilled from a solid billet. The outer diameter was 20 mm and the inner diameter was 13 mm. The metal core was the same alloy as tube blanket with a diameter of 12 mm, slightly less than the inner diameter of the tube blanket. The metal core was inserted into the tube blanket to form a drawing assembly. They were drawn together like a solid billet. Molybdenum disulphide was used as lubricant between the tube blank and the metal core

Figure 1 shows the die set up. It has a drawing die and clamping die. The clamping die has a cavity that holds the drawing die and specimen. There are also heating elements in the cavity that heat the specimen. Figure 2 shows the actual drawing process. A universal tensile machine is used. The upper jaw of the tensile machine grips one end of the specimen that comes through the drawing die. The lower jaw grips the clamping die. Graphite was used between the specimen and drawing die to eliminate friction. The dies and specimen were preheated and isothermal held at 830ºC for 1 hour before hot drawing. The drawing speed was set at 120 mm/min.

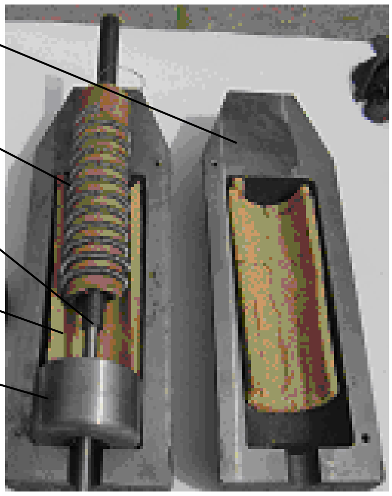


Fig. 1: *Drawing die and clamping die set up*

Fig.2: *Hot drawing set up*

3. Hot drawing process

The hot drawing follows the procedure set out below. The starting tube blank had a length of 200 mm, outer diameter 20 mm and inner diameter 13 mm. The metal core was 250 mm long and 12 mm in diameter. The metal core was coated with molybdenum disulphide and inserted into the tube blank. The assembly was annealed at 700ºC. The annealed assembly was then nosed at one end and placed into the graphite-lubricated tungsten carbide die. The other part of the assembly was placed into the heating element. The clamping die was then closed. The specimen and the claming die were gripped in the tensile machine. The specimen was heated and isothermal held at the drawing temperature 830ºC for 1 hour before hot drawing. The drawing process was took place by several drawing passes with each pass had a reduced diameter. After each drawing pass, the elongated assembly was taken out and nosed to the next step drawing die. No annealing was performed between each drawing pass. Once the final diameter was achieved after multiple drawing passes, the tube wall at both ends was scored circumferentially. The end sections of the tube (outside the score lines) and the ends of the core inside them were firmly gripped in a draw bench, and pulled apart in a single stretching step. The ends of the tube, outside the score lines, broke off immediately and the core itself was stretched plastically (about 15%). The stretching resulted in a cross area reduction of the core and a clearance was developed between the tube and core enabling the longitudinal core removal.

Multiple drawing passes were used with the diameter of the drawing die reduced from 18.5 mm, to 17.2 mm, 16.0 mm, 14.8 mm and finally 14.0 mm pass by pass. Table 1 summarizes the dimensional changes during the multiple pass hot drawing.

Table 1: Dimensional changes during the drawing process

Drawing passes	**Drawing die diameter (mm)**	**Metal core Diameter (mm)**	**Tube (mm)**		
			Outer diameter	**Inner diameter**	**Length**
Tube blank		12.0	20	13	200
1st pass	18.5				
2nd pass	17.2	11.8	17.1	11.8	208
3rd pass	16.0	11.5	15.7	11.5	212
4th pass	14.8	11.5	14.5	11.5	234
5th pass	14.0	11.0	13.6	11.0	259

Figure 3 shows the tube and metal core assembly. The metal core was inserted in the starting tube blank. The assembly was nosed in one end to a reduced diameter so it can pass through the drawing die and be clapped by the upper jaw. Figure 4 shows the assemblies being taken from the various passes of the drawing operation.

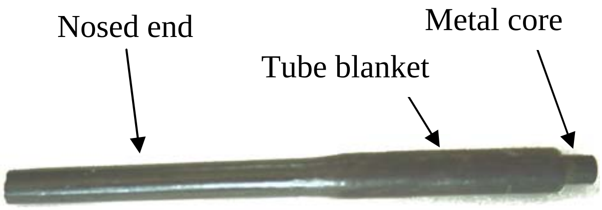


Fig. 3*: Tube and metal core assembly*

Fig. 4*: Assemblies being taken from various passes of the drawing operation*

Figure 5 shows the tube assembly that has been undergone 4 passes of hot drawing operation. The last drawing die it being passed through was f 14.8 mm die and its resultant diameter for the assembly was 14.5 mm. The last pass for this specimen was f 14.0 mm die and the final tube diameter was 13.6 mm. Figure 6a shows the assembly that has been was scored circumferentially at both ends. Then the metal core was plastically stretched and removed from the tube assembly. The final Nitinol tube is shown in Figure 6b.

Fig. 5*: Tube assembly after 4 drawing steps. The outsider diameter is 14.5 mm*

(a)

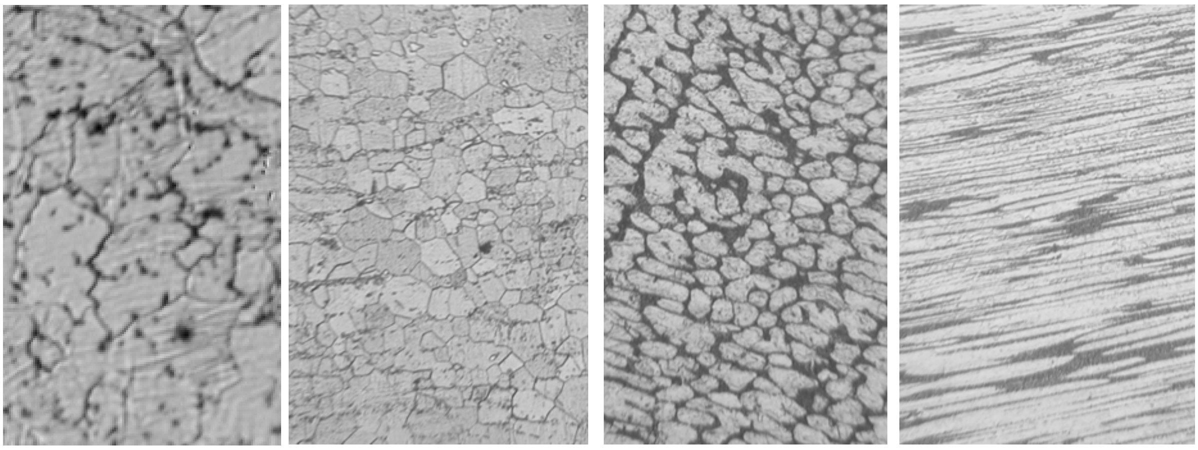
(b)

Fig. 6*: Tube assembly has been scored circumferentially at both ends (a), and the tube after the metal core has been removed (b)*

5. Microstructure and mechanical properties

Figure 7 shows the microstructures of the tube blank and the hot drawn tube. The grain structure was stretched after the drawing process, especially after multiple drawing passes, as shown in Figure 7d, which was undergone 5 passes of hot drawing. Some recrystallization occurred in the low passed drawn samples (Figure 7b).

The plastic deformation during drawing also significantly improves material's mechanical properties. Figure 8 shows the tensile curves of the tube before and after drawing. The results of the tube blank (before drawing) obtained from three specimens showed an average elongation 14.8% and tensile strength 540 MPa. After 7 passes of drawing (2 specimens), the elongation increased to 30% and



(a) (b) (c) (d)

Fig. 7: *Microstructures of the tube blanks and hot drawn tubes. (a) NiTi tube blank and (b) after 2 passes of hot drawing; (c) NiTiNb tube blank and (d) after 5 passes of hot drawing*

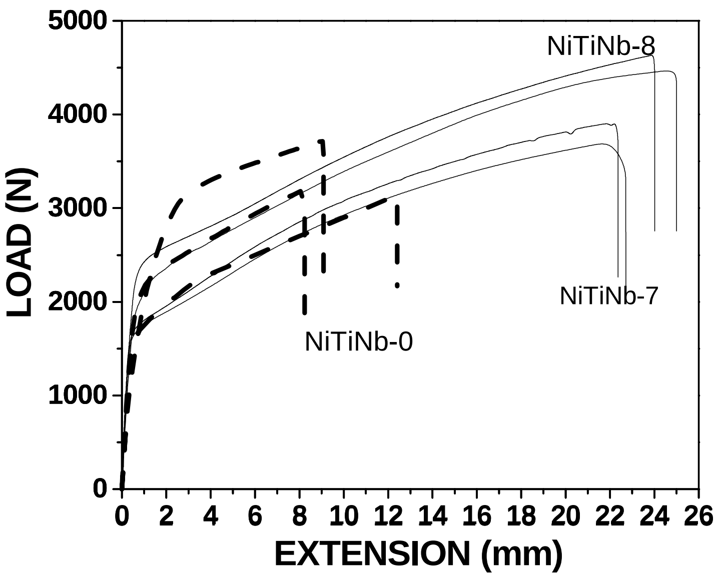
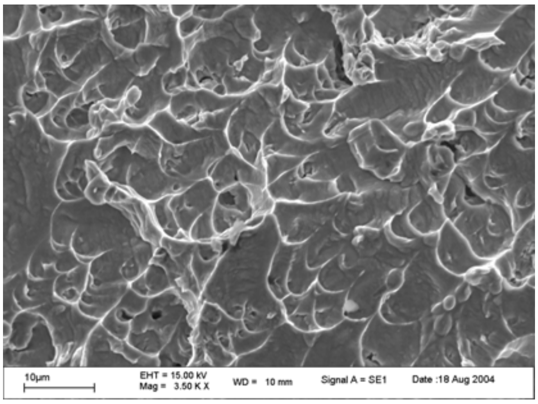


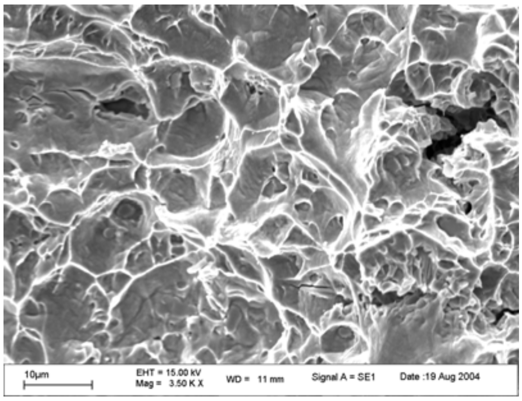
Fig. 8: *Tensile curves of NiTiNb tube before drawing and after 7 and 8 passes of hot drawing*

tensile strength to 600 MPa. With 8 passes of the drawing (2 specimens), these properties were improved further to 40% and 710 MPa. The fracture surface of the NiTi and NiTiNb alloys after 5 passes of drawing operation are shown in Figure 9. Both show typical ductile fracture features.

It is desirable that the drawing process wouldn't have an adverse effect on its shape memory properties. Figure 10 shows the thermal transformation behaviour of NiTiNb alloy without drawing, 7 passes of drawing and 8 passes of drawing. NiTiNb material exhibits a phase transformation from austenite to martensite on cooling and a reverse transformation (from martensite to austernite) on heating. The thermal transformation patterns were well preserved after the drawing operation. Slightly changes on the phase transformation temperatures were observed, as shown in the curves.



NiTi alloy



NiTiNb alloy

Fig. 9: *Fracture surface show a ductile fracture. Both NiTi and NiTiNb alloys have been undergone 5 passes of hot drawing*

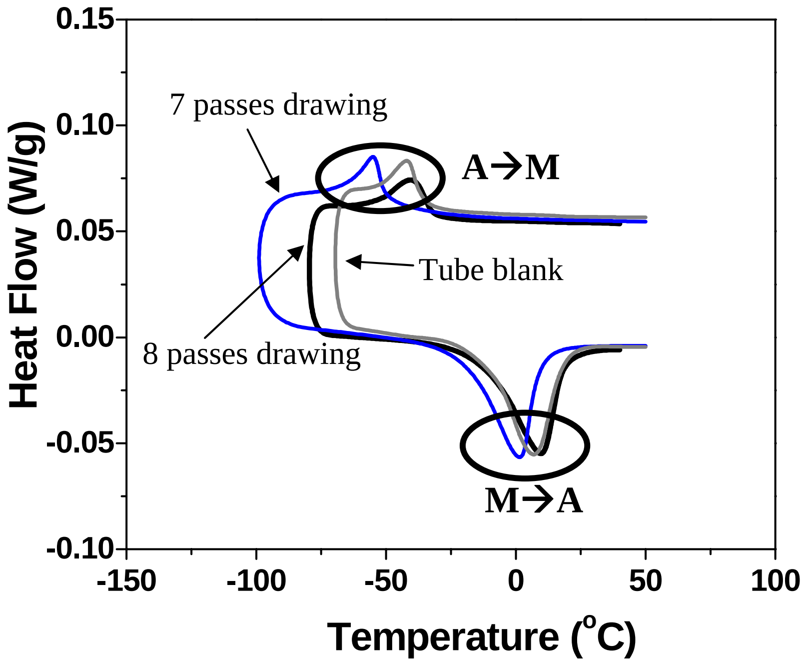


Fig. 10: *Phase transformation behaviour of the tube blank and after hot drawing*

6. Conclusions

By making use of a metal core, Nitinol tubes made from NiTi and NiTiNb alloys have been successfully hot drawn from drilled tube blanks. The Nitinol tube blank and a metal core are assembled together. The assembly is hot drawn for several passes to a final diameter. The microstructure of the materials is elongated during the hot drawing process and the plastic deformation also significantly improves its mechanical properties. The materials shape memory property is not affected by the hot drawing process.

Acknowledgement

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