STRETCH FORMED Ni-Ti SHAPE MEMORY ALLOY SHEET PART

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Abstract

In this study, a commercially acquired Ni-rich (50.0~50.8at% Ni) Ni-Ti shape memory alloy sheet having the thickness of 0.9 mm was cut in the shape of a circle with a diameter of 36 mm and placed in a heated chamber at 800°C for one hour and then quenched in water, which served as a solid solution process affiliated to an annealing process. This sheet blank was then stretch formed with a hemispherical punch of 30 mm in diameter to a stroke 1 mm, 2 mm, 3 mm, and 4 mm, respectively. After removing the punch, the formed part was then put into a furnace for aging treatment at 300°C for one hour and subsequently quenched in water. As a result, for smaller punch strokes the sheets could not be well formed, because the maximum strain presented in the alloy was little bit over the elastic region. After the aging process, the heights of the formed sheets were extra shortened because of a further springback. The springback after stretch forming and during aging can be compensated by modifying the punch radius, so that a tolerable shape with shape memory effect can be achieved with only one die set. Furthermore, if the sheet part was immersed in liquid nitrogen basin to have its martensitic phase and compressed into a flat shape, the original shape of the part can be fully recovered by returning to room temperature.

Keywords: Ni-Ti shape memory alloy, sheet metal forming, stretch forming, shape memory

1. INTRODUCTION

Because of its superior properties in shape memory effect and superelasticity by changing temperature to have a transformation between its martensitic and austenitic phases, the shape memory alloys can serve as smart materials in transducer and sensor applications. Most of Ni-Ti alloys, which are the most used shape memory alloys, are in austenite phase at room temperature, showing high strength and being hard to deform. The conventional process to form shape memory alloys into shapes and have them possess shape memory effect is to form the alloys with a pair of dies in hot state, keep the alloys and the dies in a constraint state inside a heat treatment furnace to develop the shape memory effect by aging, and then quench the alloys in a water basin [1]. To reduce the use of expensive die sets in the forming and the constraint aging process at elevated temperature, it might be worthwhile to try forming the shape memory alloys at room temperature in order to see their form accuracy and shape memory effect in cold state and after the subsequent heat treatment without additional dies [2]. This study is thus aimed to investigate the feasibility of the above proposed processes for shape memory alloy sheet part: cold forming with only one die set and aging without any further die set.

2. STUDY SETUPS

In this study, a commercially acquired Ni-rich (50.0~50.8at% Ni) Ni-Ti shape memory alloy sheet having the thickness of 0.9 mm was cut in the shape of a circle with a diameter of 36 mm and placed in a heated chamber at 800°C for one hour and then quenched in water, which served as a solid solution process affiliated to an annealing process. This sheet blank was then stretch formed with a hemi-spherical punch of 30 mm in diameter to a stroke 1 mm, 2 mm, 3 mm, and 4 mm, respectively. **Figure 1** shows the schematic setup and the apparatus for the cold stretch forming process. For each stroke a separate bottom die is equipped. The forming process is executed in a universal testing machine.

After removing the punch, the formed part was then put into a furnace for aging treatment at 300°C for one hour and subsequently quenched in water. The shape memory effect of the stretch formed parts was investigated as well by checking the height of the sheet parts recovered by returning temperature to the austenitic phase completely presented after compressing them into a flat shape at a temperature, at which the martensitic phase is completely presented.

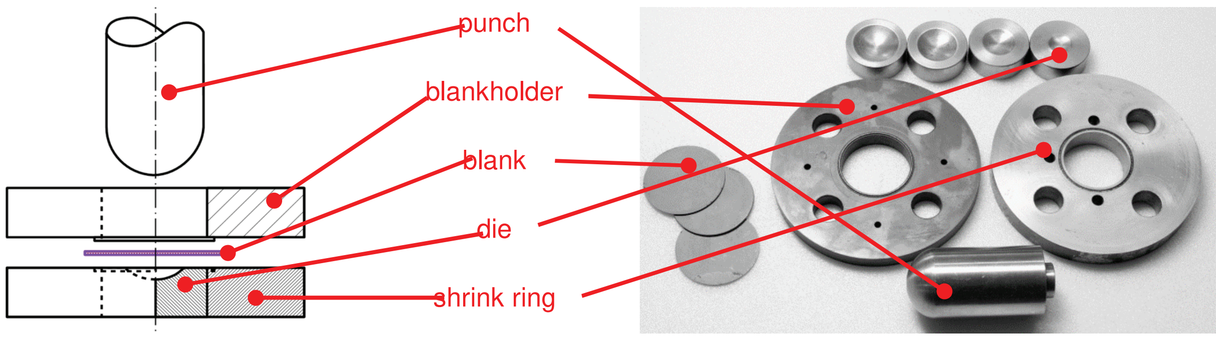

Figure 1 Experiment setup

3. RESULTS AND DISCUSSION

Figure 2 shows the stress-strain diagram of the at 800°C solid-solved Ni-Ti shape memory alloy sheet in a tensile test at room temperature. The shape memory alloy shows a large linear elastic strain range around 3% and has no evident necking before fracture but still shows a large ductile strain over 20%. Because the sheet has its austenitic phase at room temperature, it is hard to deform and shows a strong strain hardening effect.

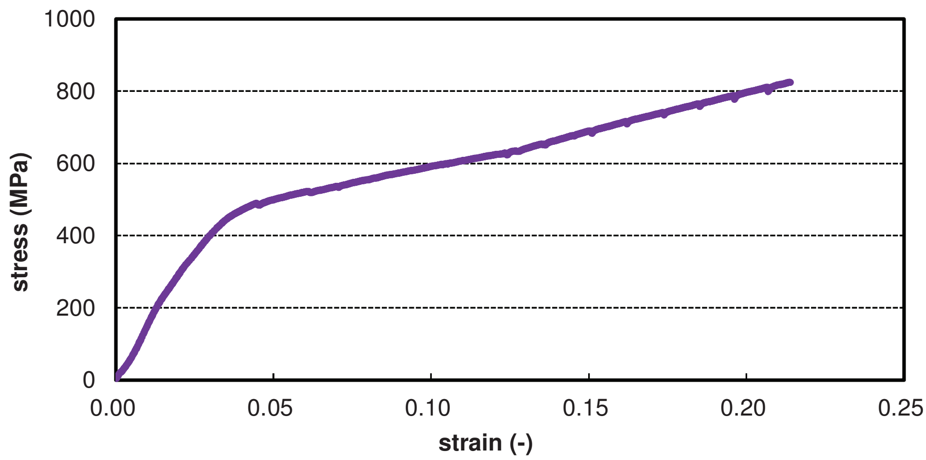

Figure 2 Stress vs strain of Ni-Ti shape memory alloy sheet in tensile test

Figure 3 shows the punch load to the sheet blanks in the different forming strokes at room temperature. The punch load during downward stroke was higher than that during upward stroke, because there was plastic deformation downwards whereas only elastic springback. The springback was relatively high and its load vs stroke curve was not linear either. The load was almost fully recovered at the early upward stroke but for the latter stroke upwards the load decayed very slowly. It also shows the hysteresis. The larger the area enclosed, the more the plastic deformation and the better the form precision. As shown in **Figure 3**, the higher the punch stroke, the larger is the area and therefore it is expected that the less the springback and the more precise the part formed. The curves for downward and upward stroke almost overlap each other for the forming stroke of

1 mm. It means that the formed geometry almost sprang back to flat shape, which can be observed in **Figure 4**. The part for the forming stroke of 2 mm is also hard to see the formed shape.

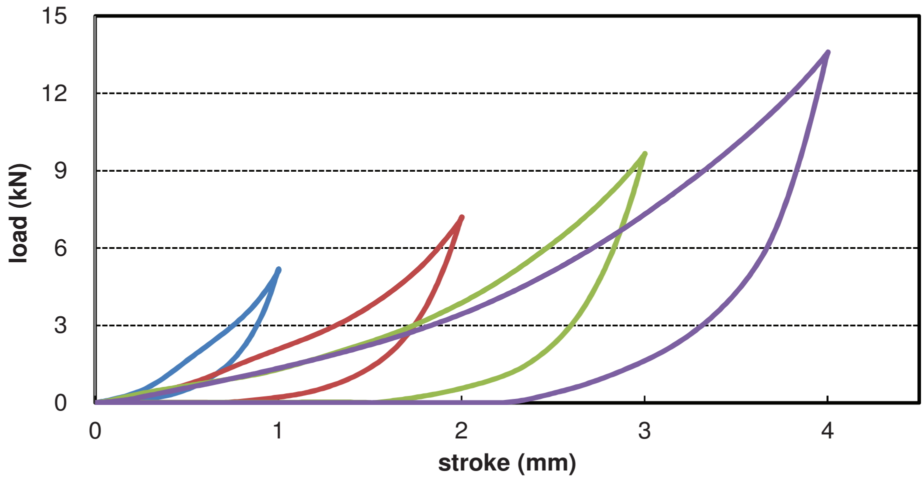

Figure 3 Load vs stroke during stretch forming under different strokes

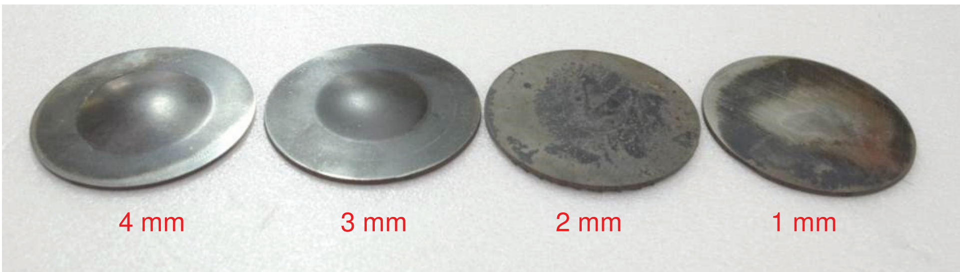

Figure 4 Stretch formed shape memory alloy parts under different strokes

If the stretch formed part is taken on a coordinate measuring machine (CMM) and its whole geometry is read in a pitch of every 0.02 mm by a probe with diameter of 1 mm having a resolution of 0.001 mm, it can be found that in comparison to the die geometry, which is drawn in dash line, the dome of the formed part is relative flat by springback as shown in **Figure 5**. It can be also observed that the flange near to the formed region has risen because of the springback in the corner due to the pure bending process there as well.

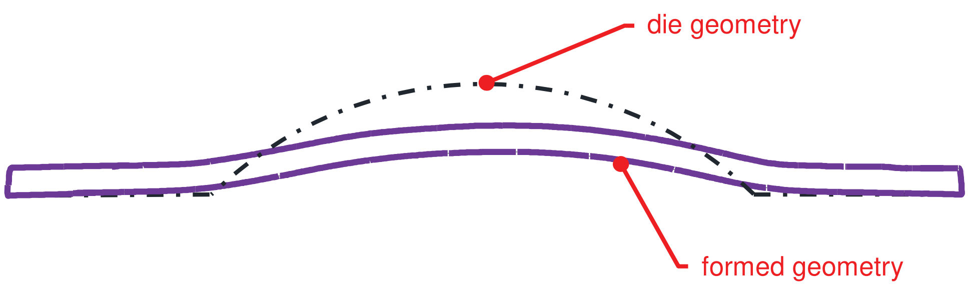

Figure 5 Stretch formed shape memory alloy part profile vs die geometry

It shows as well in **Figure 3**, that the punch load for the lower stroke was always higher than that for the higher stroke while the punch was at the same stroke. It can be attributed to that the blank was clamped by the blankholder and the bead on the blankholder bit the blank before the forming stroke to restrict the material of the blank from the flange on the blankholder into the die cavity, so that it needed more force to form the blank.

At room temperature, all the formed and subsequently aged parts had their austenitic phase and demonstrated a shape memory effect as well after a compression to the flat shape in a liquid nitrogen basin, in which the temperature is lower than -196°C and the martensitic phase is fully presented in the parts. **Figure 6** shows that all the flatted parts almost recovered their formed shapes after returning to room temperature. The designed height shown in blue stripe is the punch stroke or the die depth, while the formed height in red is the height of the formed part after springback or the punch force released and the recovered height in green is then the height of the formed part after the temperature returning to the room temperature following the flattening process at -196°C.

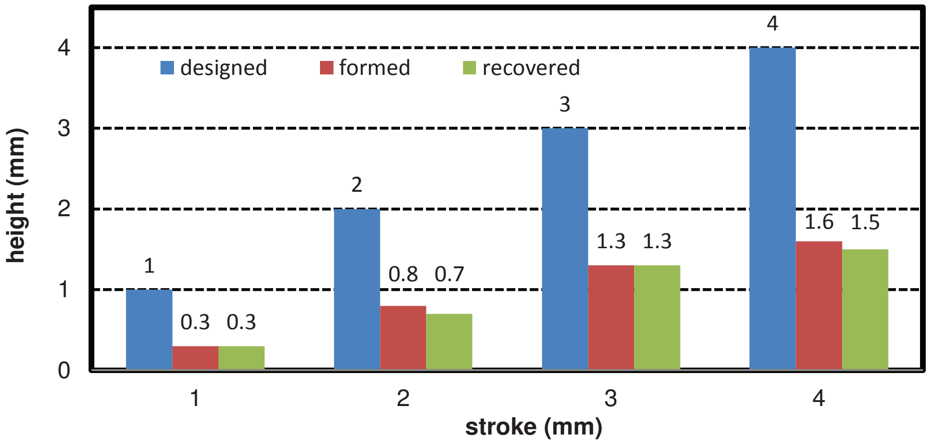

Figure 6 Load vs stroke during stretch forming under different strokes

4. CONCLUSION

It can be concluded that the process proposed by this study - to stretch form a shape memory alloy sheet at room temperature to have a shape with shape memory effect by means of a solid solution treatment before and an aging treatment after cold forming - is feasible. The springback after stretch forming and during aging can be compensated by modifying the punch radius, so that a tolerable shape with shape memory effect can be achieved with only one die set. It might be investigated how the sheet parts undergo a constrained recovery by clamping them in a liquid nitrogen basin and returning to the room temperature.

ACKNOWLEDGEMENTS

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