JOURNAL DE PHYSIQUE
Colloque C4, supplément au n° 12, Tome 43, décembre 1982 *page* C4-839

BEHAVIOUR OF WELDED PART OF Ti-Ni SHAPE MEMORY ALLOY

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(Accepted 9 August 1982)

Abstract

Thin wires of Ti-Ni shape memory alloy are welded without fusion or cast zone by the resistance butt welding. The weld current is fed to the butt welded parts with little offset during the time shorter than that in the forging process. The tensile strength of the welded part is attained over 80 percents of that of the base metal. For checking the shape memory effect, the recovery from bending deformation for the welded parts is tested in comparison with that for the base metal, and the residual strain after the recovery is experimentally related to the ratio of latent heat of martenstic transformation to that of reverse transformation, measured by the differential scanning caloriemeter.

1. Introduction

The Ti-Ni shape memory alloy named Nitinol is one of advanced materials as heat sensitive working elements. In order to develop various applications of Nitinol, it becomes increasingly important to study the properties of welded part of this shape memory alloy, however, not a great deal has been reported on the welding. There is only a few reports on fusion weld of Nitinol using the electron beam welding and Heli arc welding.[1,2] These fusion zone are characterized by the fine dendric structure in recrystallization not to expect good shape memory effect. And it is reported that the tensile strength of these weld parts is relatively low as compared with that of base metal. By using resistance upset butt welding, it is possible to attain the weldment without fusion zone or cast zone to keep the shape memory effect.

In this experiments, the welding is carried out by using the specially designed resistance upset butt welding and the properties of welded part of Ti-Ni shape memory alloy are investigated. Welding condition for sound weldments is obtained by ultimate tensile test. The shape memory effect is checked by the recovery from bending deformation for the welded parts in comparison with that from the base metal and an index of the shape memory effect for weldment is represented by the ratio of latent heat of martenstic transformation to that of reverse transformation, measured by the differential scanning caloriemeter.

2. Experimental

Material of test pieces used in this experiment was the thin wire of Ti-50 at % Ni shape memory effect alloy• with the diameter of 0.73 mm as received and was in the temperature range of martensitic transformation from 59 C to 65 C. The test pieces were pickled after the heat treatment in vaccum for 30 minutes at 400 C. The edge of test pieces was grinded in flat. The test pieces were welded by the resistance upset welding machine specially designed for this wire, equipped with

• produced by Furukawa Electric Company

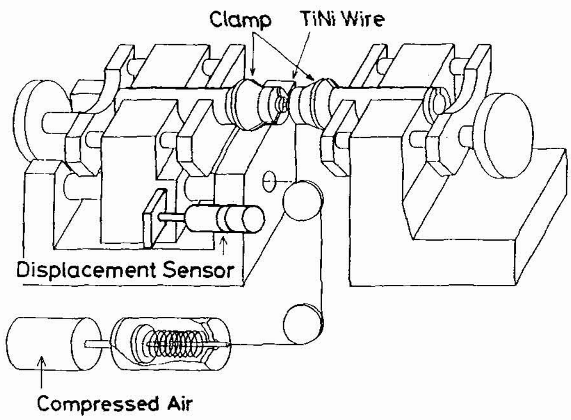

Fig.1 Schematic of resistance butt welding machine

condenser bank as shown in Fig.1. The upset force was able to be kept an arbitrary constant value from 50 N to 200 N by the spring. The weld current was changed from 385 A to 600 A at the peak value by setting the charge voltage. Figure 2 shows the typical oscillographs of the weld current, the voltage and the displacement between the electrodes. The weld current is fed to the faying weld parts with little offset during the time of 7 msec. shorter than that in the forging process where the fusing zone is extruded outward from observing the displacement between the electrodes. At the start of welding, the oscillograph of displacement shows a little negative value. It means that the electrode moves backward due to thermal expansion. In the forging process it takes about 15 msec. after the Joule heating near the butt parts. The influence of the offset on the ultimate tensile strength is shown in Fig.3. The tensile strength measured after

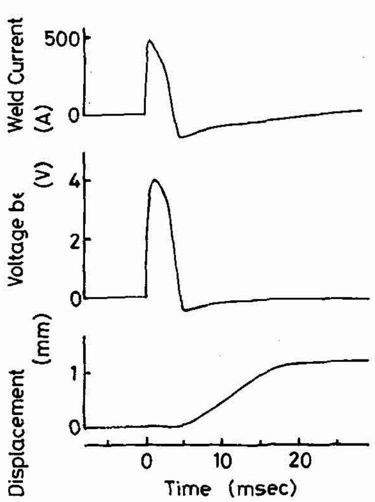

Fig.2 Oscillographs of weld current, voltage and displacement between the electrodes

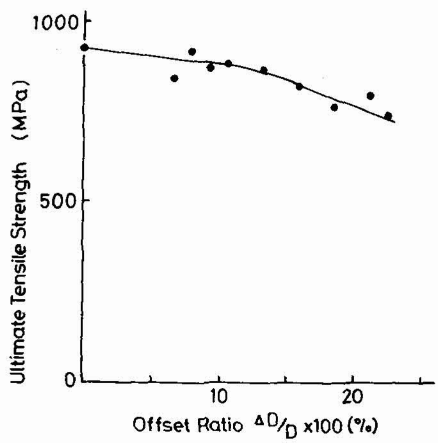

Fig.3 Effect of the offset ratio on ultimate tensile strength

triming the butt weld part decreases with increasing the offset ratio. The offset ratio is responsible for one of the scatterings of the tensile strength. In this experiment the offset was regulated within 5 percents of the diameter of the test piece so the influence of offset on the tensile strength was able to be negligible.

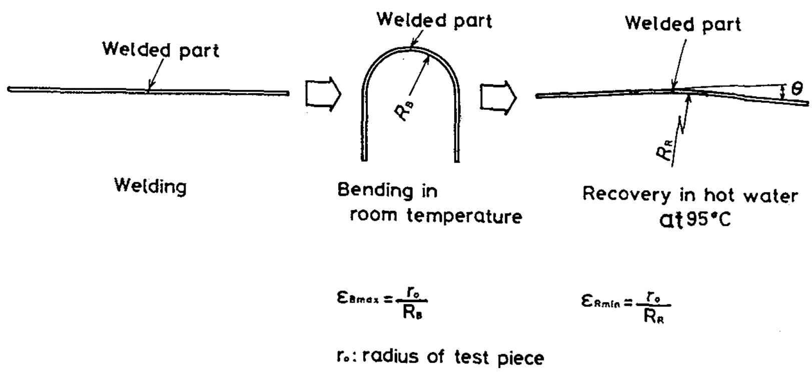

Fig.4 Bending test for checking the memory effect of the welded part

For checking the shape memory effect, the recovery from the bending deformation was tested in hot water at 95°C and the residual strain of the weld part was measured in comparison with that of base metal, as shown in Fig.4. The relative latent heats of martensitic and reverse transformation were measured by the defferential scanning caloriemeter usuing the weld part with 1 mm length cut by the slicing machine.

3. Results

The effect of the weld current (peak value) on the ultimate tensile strength is shown in Fig.5. The ultimate tensile strength increases with the weld current until 500 A and near 500 A, shows the peak value, followed by decreasing as further increase of the weld current. When the Joule heating at the butt parts becomes effective, the welded part is extruded outward by the plastic flowing to appear a clean surface at the butt part, and the value of ultimate tensile strength is also increasing until the weld current of 500 A. When the Joule heating is more extensively, the weld part is flashed out to reduce the tensile strength. The upset force is necessary to be applied as matching the plasyic flowing. If the upset force is set to a high value, the welded part is buckling not to appear the clean faying surface. On the other hand, if the upset force is set to a low value less than 50 N, the welded part is flashed out. Fig.6 shows the welding condition on the sound

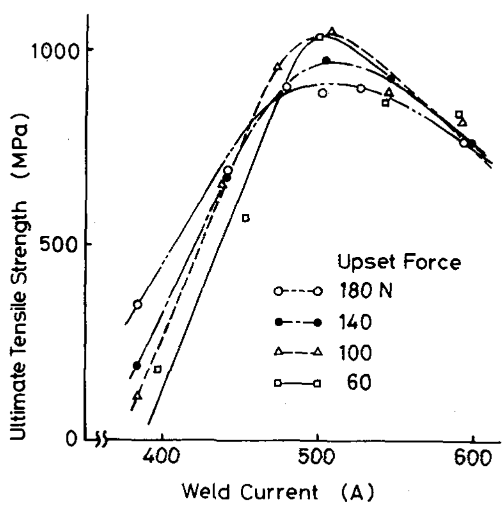

Fig.5 Relation between the ultimate tensile strength and the weld current (peak value) for various upset force

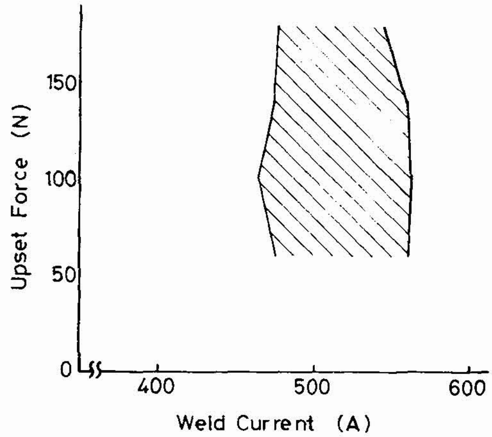

Fig.6 Welding condition on the sound weldment with ultimate tensile strength more than 80 % of the base metal strength

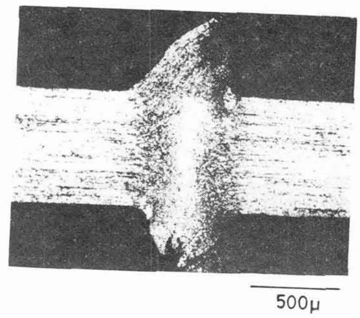

Fig.7 Typical macroscopic welded part

weldment with the ultimate tensile strength more than 880 Mpa i.e. 80 % of the base metal strength. The macroscopic structure of the sound weldment is shown in Fig.7. The weld is found to be formed as the pressure welding between clean faying surfaces extruded by the upset force. The dendric structure is not observed in this welding, as opposed to the electron beam welding and Heli arc welding. For checking the shape memory effect, the recovery from the bending deformation was tested as shown in Fig.4. The applied maximum strain was 10 percent (R_B=3.65 mm). After the recovery from the bending deformation, the residual strain of the base metal was about 0.6 to 0.7 %. The residual strain of the weld part after the recovery is plotted in Fig.8. The circle, the trigonometric and the quadrangular points represent group of the residual strain less than 1.35 %, group of the residual strain from 1.35 % to 1.50 % and group of the residual strain more than 1.50 %, respectively. The line AB represents the boundary curve of the group of the residual strain less than 1.35 %. The region surrounded the solid lines is the welding conditions for the sound weldments. The region above the dotted line AB is found to be the welding with good shape memory effect (the region marked the circle points).

The typical behaviours of latent heat of martensitic transformation and the reverse transformation are shown for the welded part and the base metal respectively in Fig.9. For the base metal annealed at 400°C for 30 minutes, the first exothermic peak appeared in the martensitic transformation near

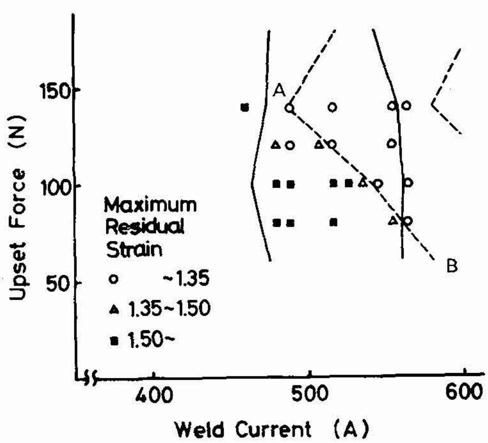

Fig.8 Maximum residual strain after the recovery from bending deformation for checking the shape memory effect

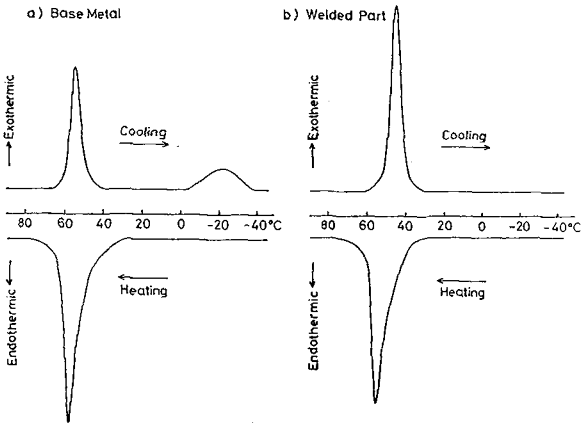

*Fig.*9 Endothermic and exothermic phenomena associated with martensitic and reverse transformations

55°C, followedby the second exothermic peak near -20°C as cooling. On the reverse process as heating, the endothermic peak was not observed near -20°C except the endothermic peak near 55°C. On the other hand for the welded part,only the first exothermic peak was observed as cooling and on the reverse process as heating only one endothermic peak was also observed near 60°C. The exothermic calorie (Q_M) and the endothermic calorie (Q_A) are postulated to be related to the shape memory effect due to martensitc transformation of the metal in working or forming. If the ratio of latent heat of martensitic to reverse transformation ($I=Q_M/Q_A$) will be a index of the shape memory effect, the index of the base metal annealed at 400°C for 30 minutes is calculated to be 0.7. *Figure* 10 shows the ratio of latent heat of martensitic to reverse transformation for the parts welded in various welding conditions. The welding conditions surrounded the dotted line in Fig.9 correspond to those with the index value from 0.6 to 0.8. The curve AB is found to be agree with one of the boundary curves on the welding conditions with the index value of 0.8. The welding conditions with good shape memory effect is found to the correspond those with the index value less than 0.8 on the welding conditions for sound weldments.

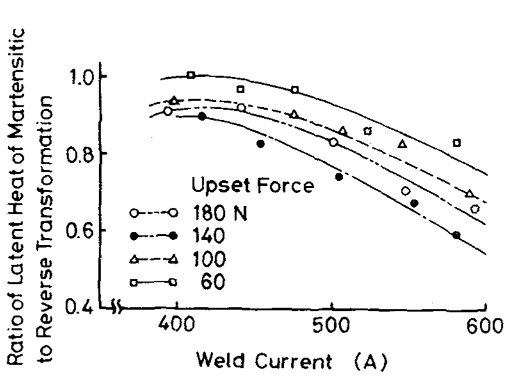

Fig.10 Relation between the ratio of latent heat of martensitic to reverse transformation and the weld current

4.Conclusion

Thin wire of Ti-Ni shape memory alloy was welded without fusion or cast zone by the resistance butt welding in the atmosphere. The ultimate tensile strength was attained to be more than 880 Mpa i.e. 80 % of the base metal strength. The shape memory effect of the welded part was found to remained after the welding by checking the recovery from a bending deformation. The residual strain after the recovery was experimentally related to the ratio of latent heat of martensitic transformation to that of reverse transformation.

Refferences

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